NOvA Near Detector

Fermilab PAC meeting
Snowmass, CO
27 June 2010

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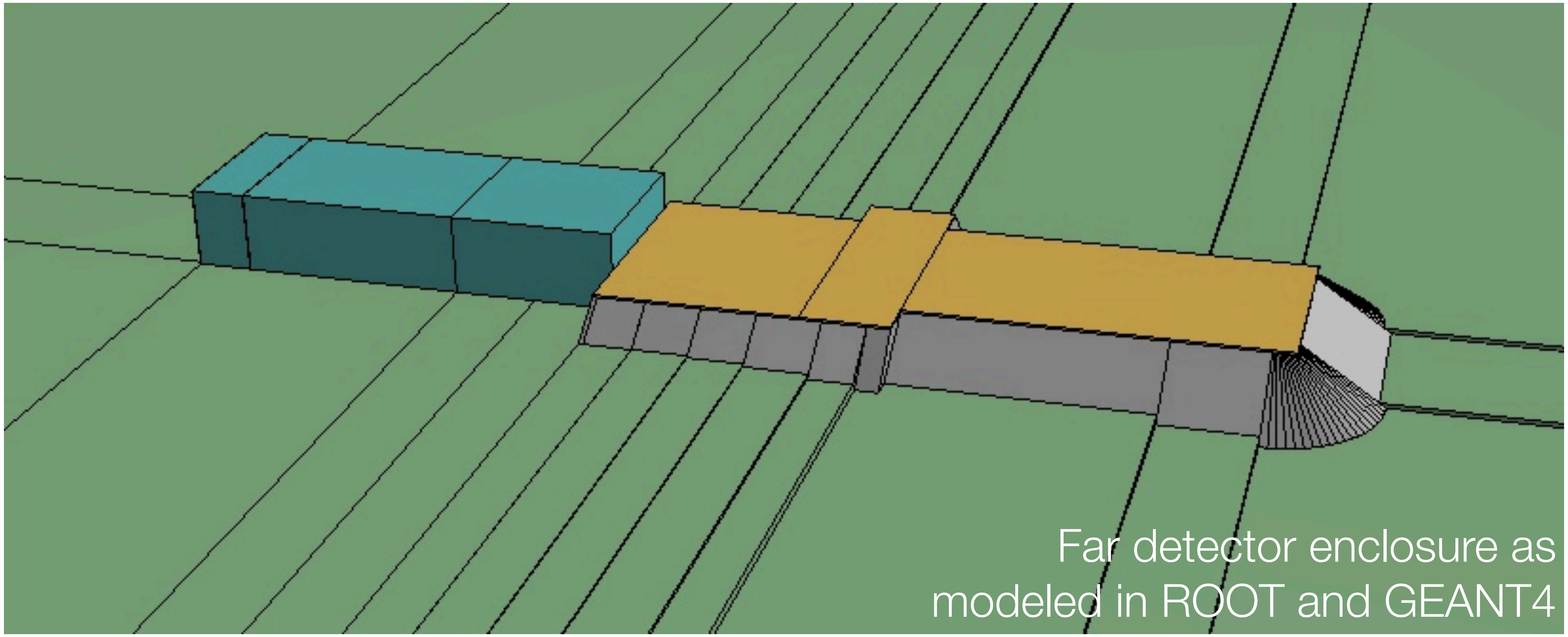
Indiana University / Caltech

Outline

- **Highlights of recent experiment progress**
  - *Not really part of my charge, but it has been a while since we reported to the PAC. Most of this summary is in the backup slides.*
- **Prototype near detector installation on surface (NDOS)**
  - Overview of the installation
  - Summary of lessons learned
  - Results from recent data
- **Near detector plans for the experiment**
  - Wider near detector
  - SciNOvA
  - Additional near detector cavern



Experiment progress:

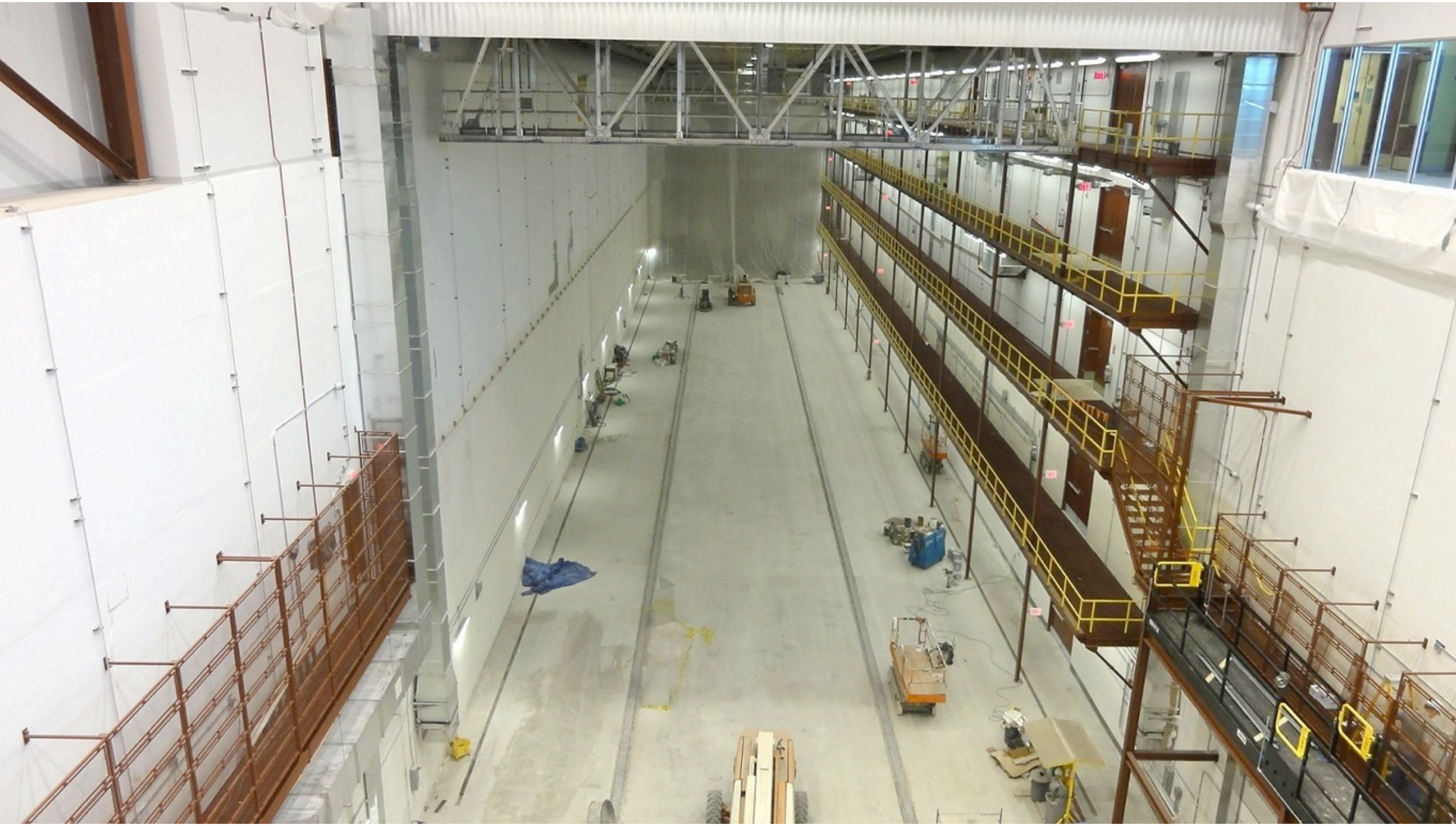
Far detector laboratory complete

After many years of looking at this. We can now look at this...

Experiment progress:

Far detector laboratory complete

Beneficial occupancy of Ash River laboratory on April 13, 2011



Experiment progress:

Far detector laboratory complete

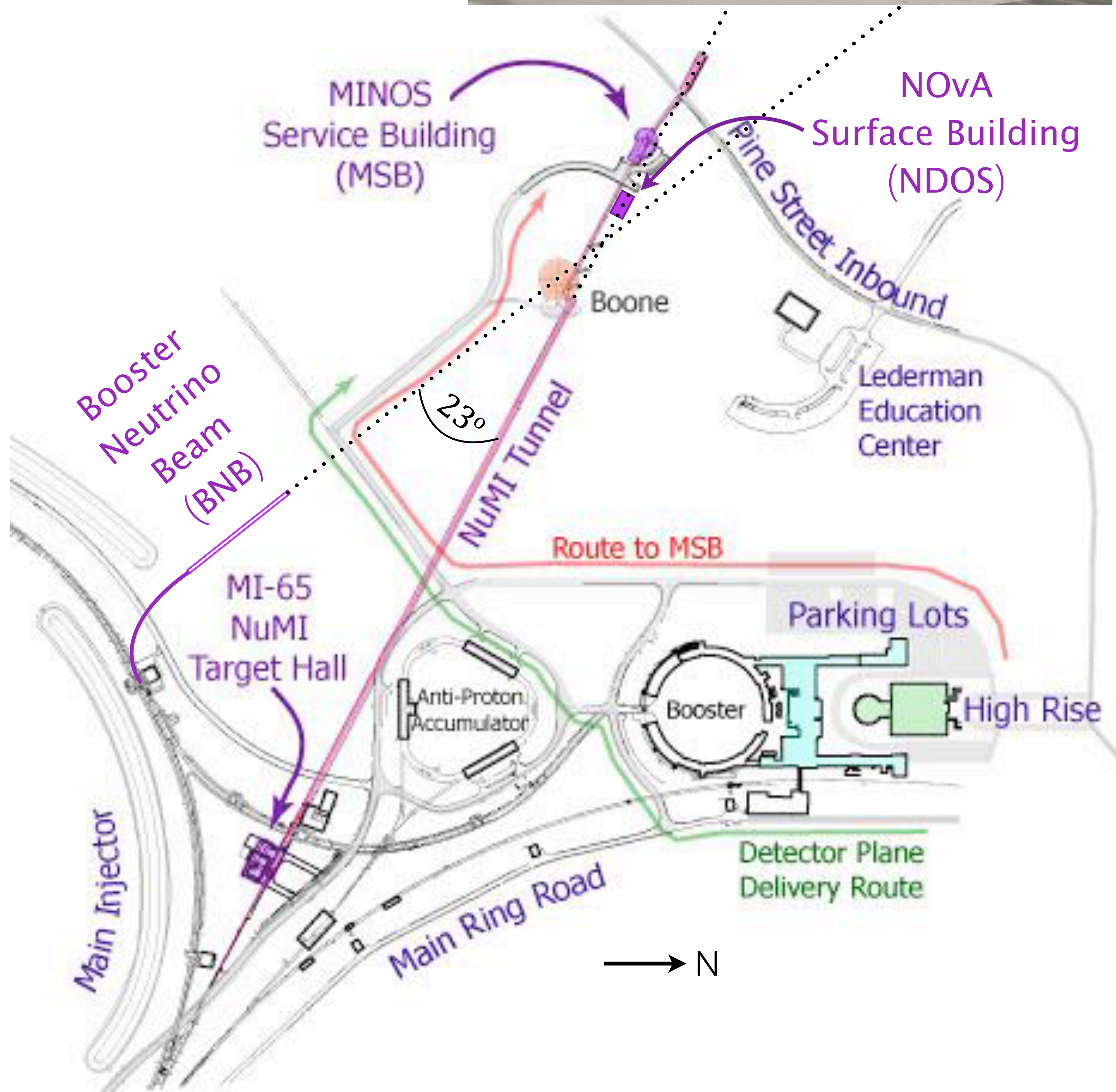
Inside the detector enclosure looking south

Near Detector On Surface (NDOS)

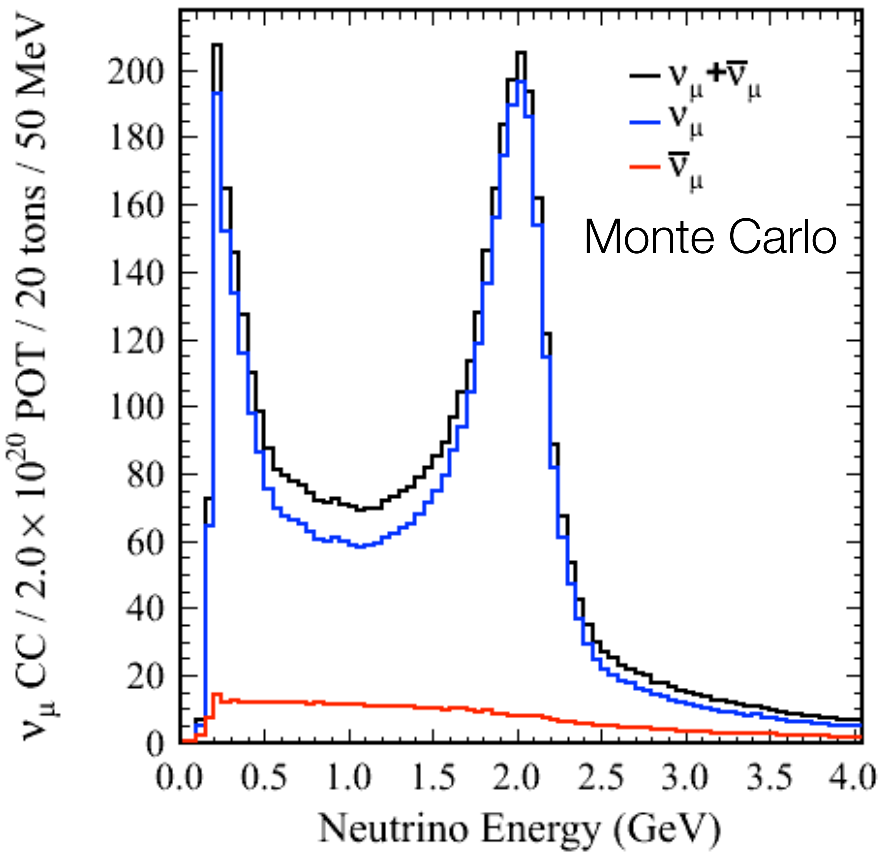
- Designed to prototype all detector systems prior to installation at Ash River as a full end-to-end test of systems integration and installation
- 2 modules wide by 3 modules high by 6 blocks long. Far detector is 12×12×30. NDOS mocks up upper corner of far detector ~exactly.
- Installation completed May 9, 2011.
- Commissioning and data collection on going 11/2010 - present

NDOS location

- Located in two neutrino beams providing an early look at data and a chance to tune up DAQ, calibration, reconstruction, and analysis prior to first data from Ash River
- NDOS is located directly above the NuMI neutrino beam line and is oriented parallel to the NuMI beamline. It sees neutrinos at an off-axis angle of 110 mrad.
- NDOS is located ~on the Booster Neutrino Beam (BNB) line, but the detector axis is rotated 23^o with respect to the BNB beamline

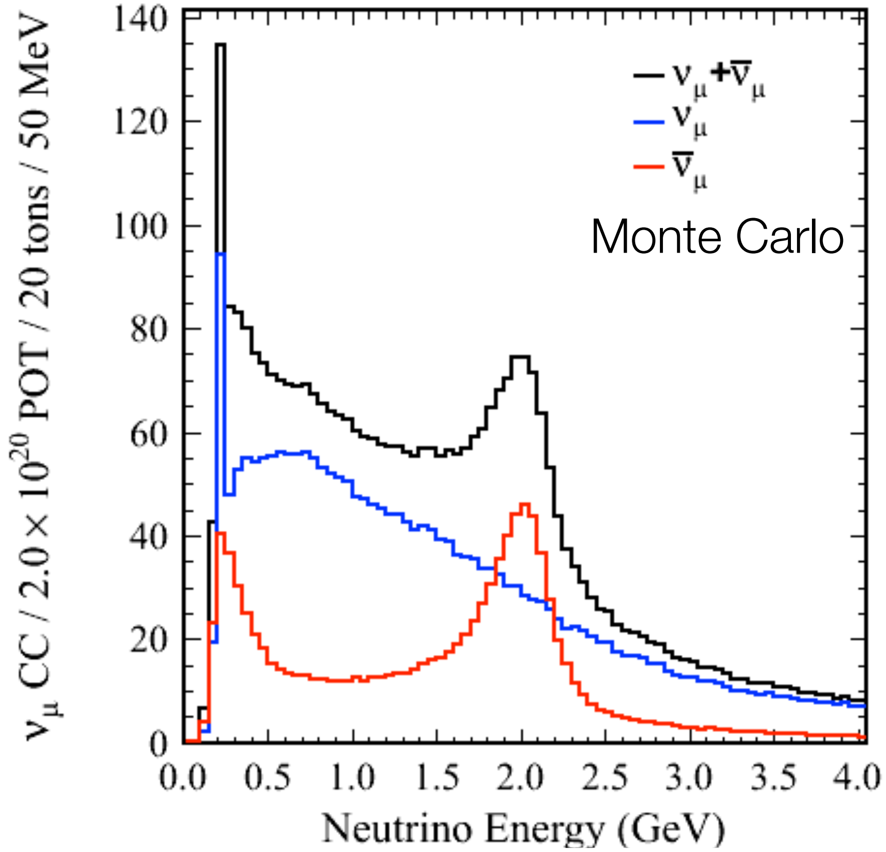


NuMI Neutrino Beam



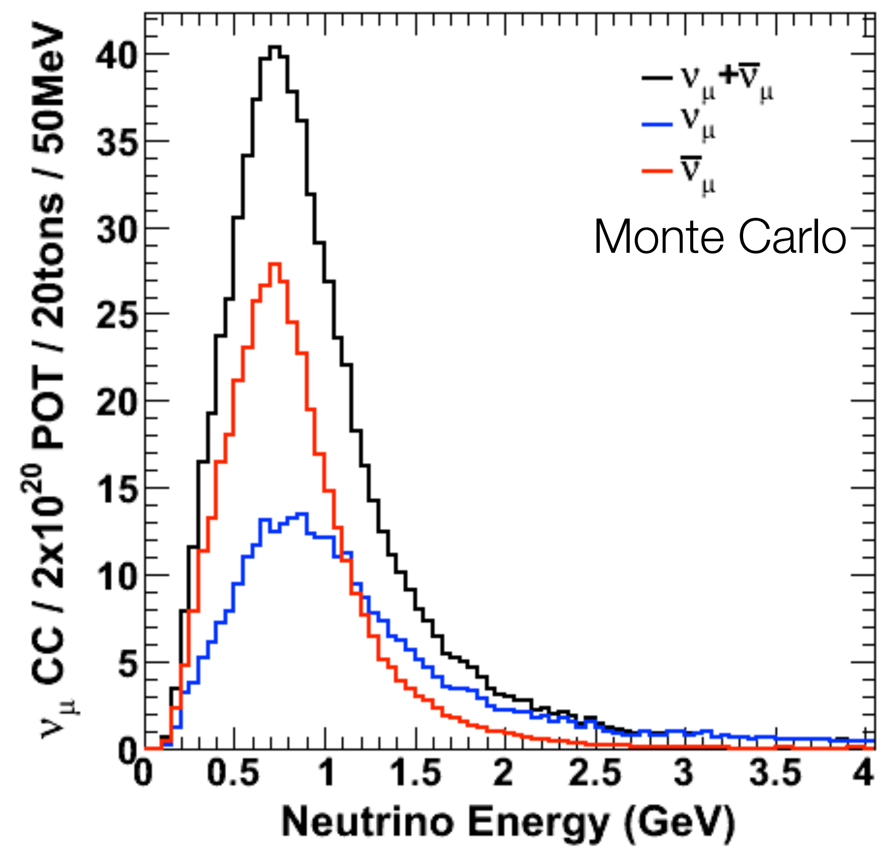
4500 events / 20 tons / 2E20 POT

NuMI Antineutrino Beam



3300 events / 20 tons / 2E20 POT

Booster Antineutrino Beam



735 events / 20 tons / 2E20 POT

NuMI Beam

- In neutrino running kaon decays produce a peak at 2 GeV - a good match to the 2 GeV peak from pion decay at 14 mrad to be used in experiment.
- In antineutrino beam, the wrong-sign contamination washes the 2 GeV peak out.
- We've taken 5.6E19 POT in antineutrino mode and 8.4E18 POT in neutrino mode.

BNB Beam

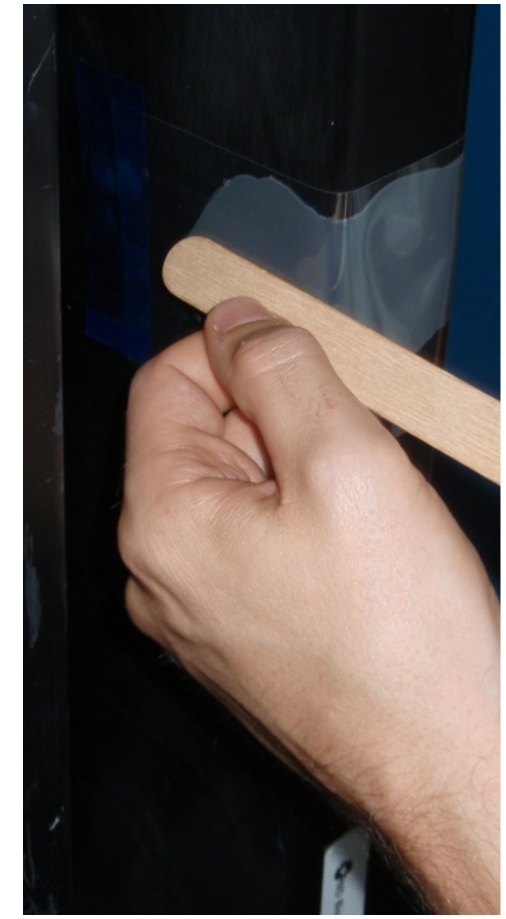
- Peaks at 700 MeV
- We've taken 2.7E19 POT in antineutrino mode

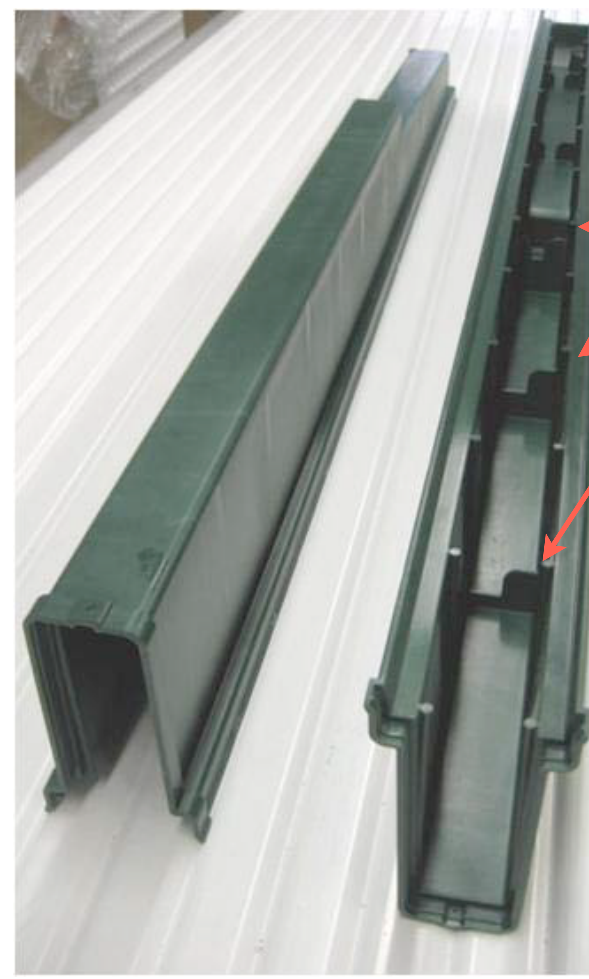
NDOS lessons learned

- NDOS has allowed us to work out numerous installation and integration issues; accessibility of hardware components, interference between various hardware components, etc. etc.
- I will spend some time on a few major issues that NDOS has allowed us to resolve:
  - Manifold cracks
  - APD/FEB noise
  - APD installation

Lesson learned: Manifold cracks

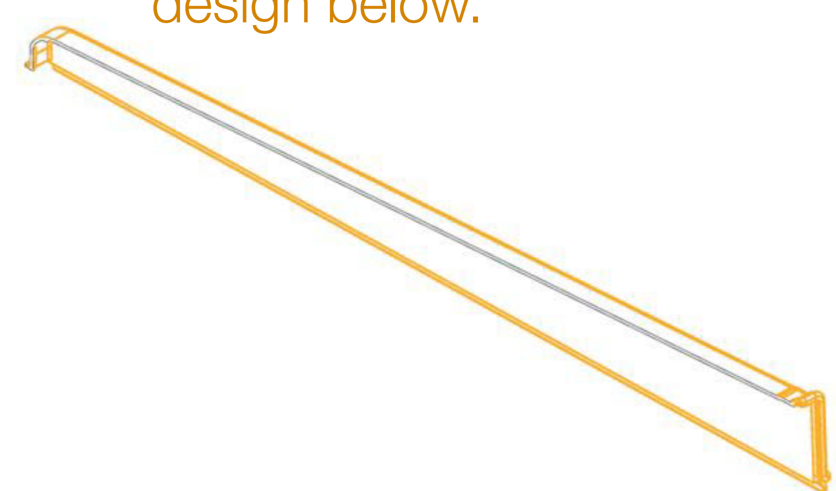
- About 20% of manifold covers developed cracks prior to being filled with scintillator. One leaked after fill.
- Initiating event identified as pressure leaks tests. Cracks propagate along stress points identified using FEA analysis
- Repairs and preventative actions taken on all NDOS manifolds. No leaks in repaired pieces.
- Designed for far detector to be stronger and to eliminate stress concentrators. Pressure testing procedures modified.





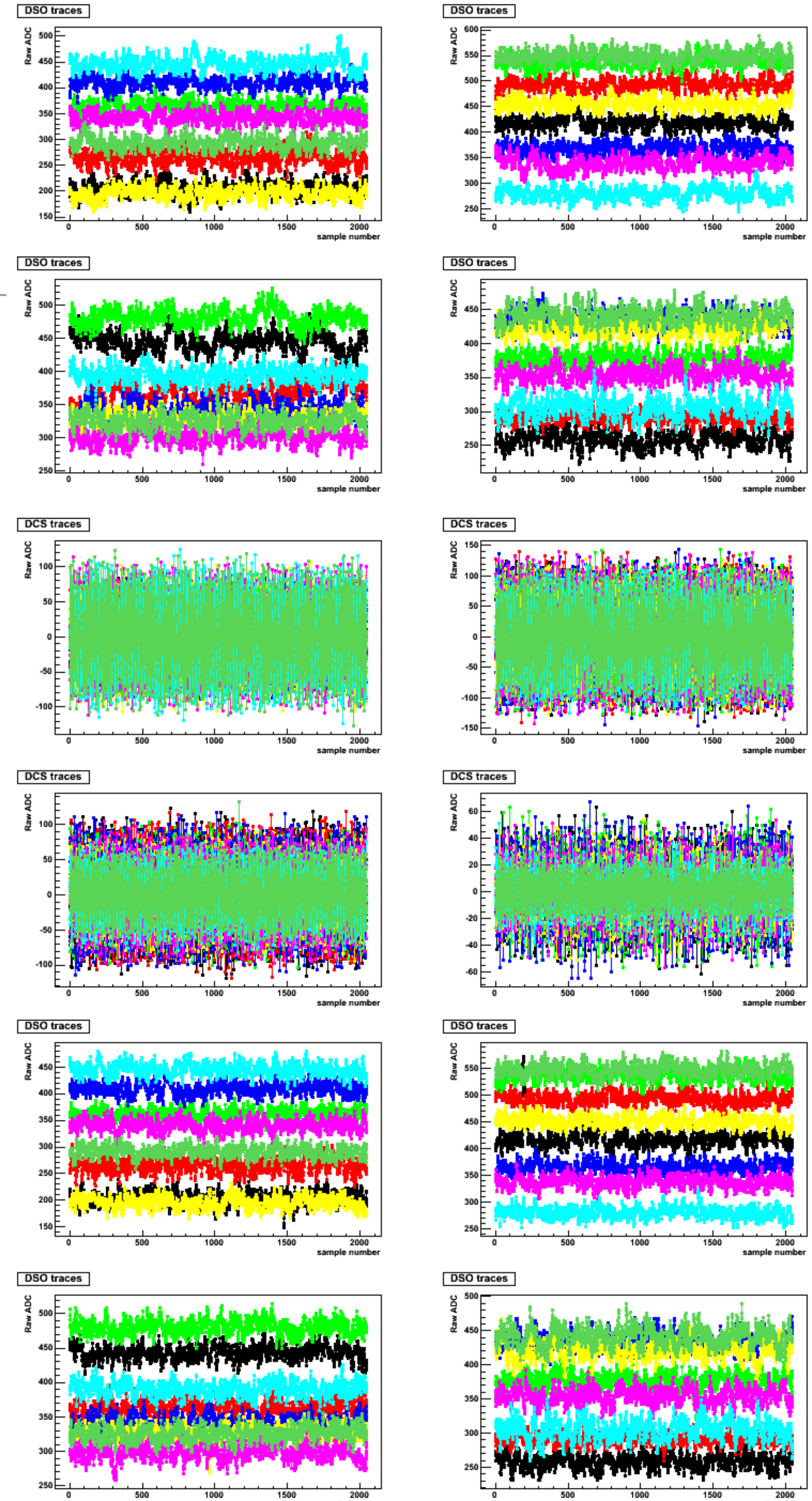
Ridges and ribs concentrate stress.

Eliminated in new design below.



Lesson learned: TECC noise

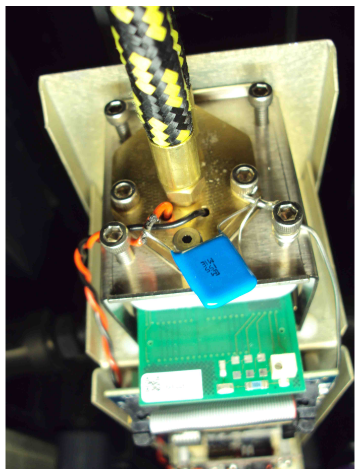
- Normally the front end boards produce time and charge signals using a dual correlated sampling algorithm but they can also be programmed to run in “digital oscilloscope” (DSO) mode where they pass the full digitized wave form on to the DAQ.
- DSO operation has proved essential for evaluating pedestal noise, setting channel thresholds, and debugging.
- For example: The thermoelectric cooler control circuit uses a switching control circuit that was found to be noisy. Additional capacitive coupling to the heat sink reduces this noise to acceptable levels.



TECC OFF

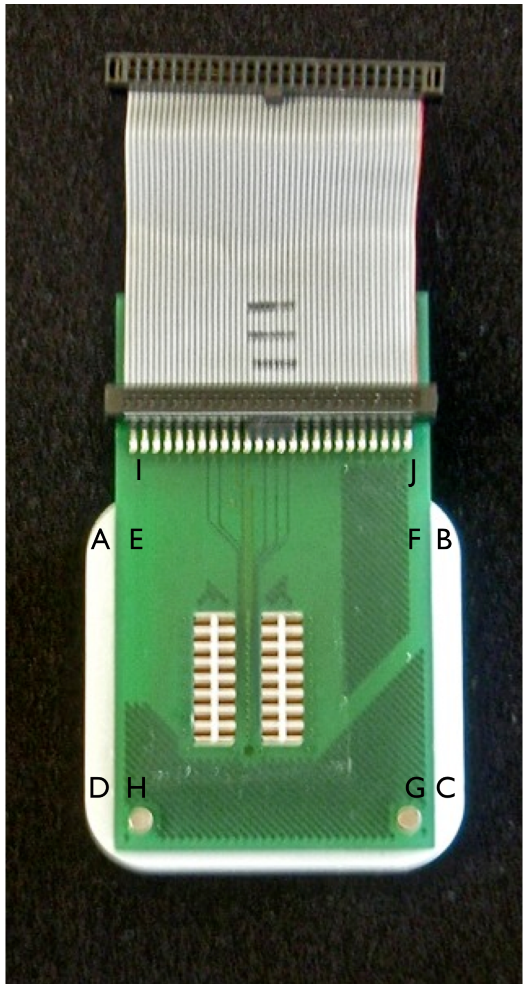
TECC ON

TECC ON w/ cap

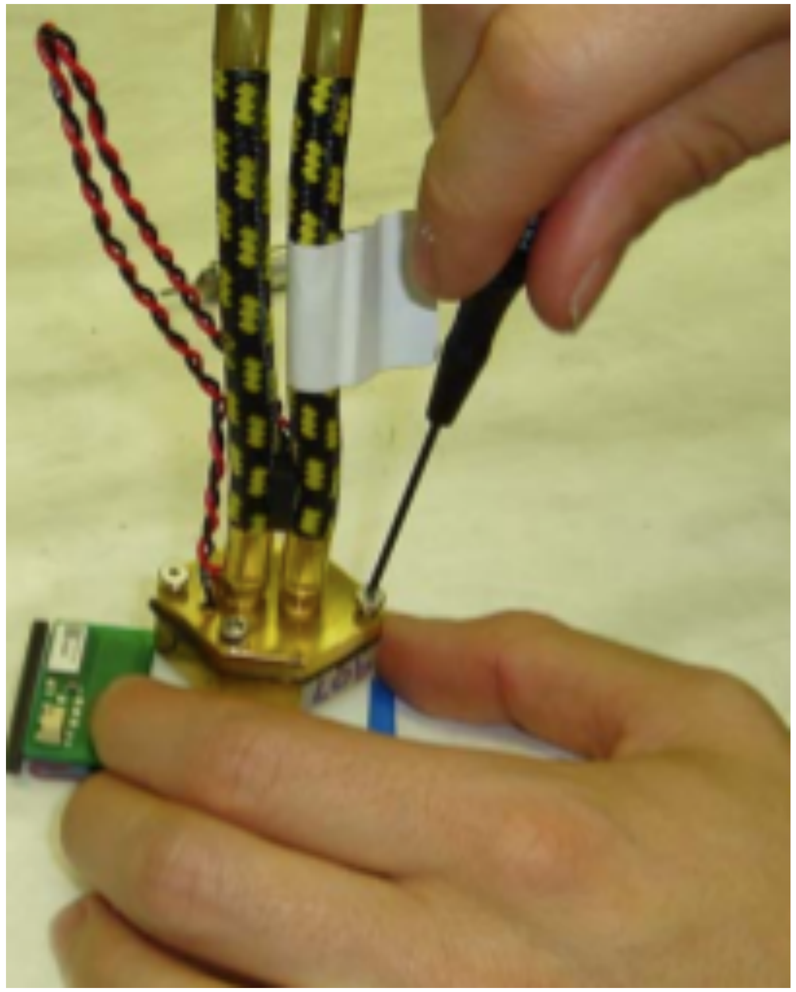


Lesson learned: APD installation

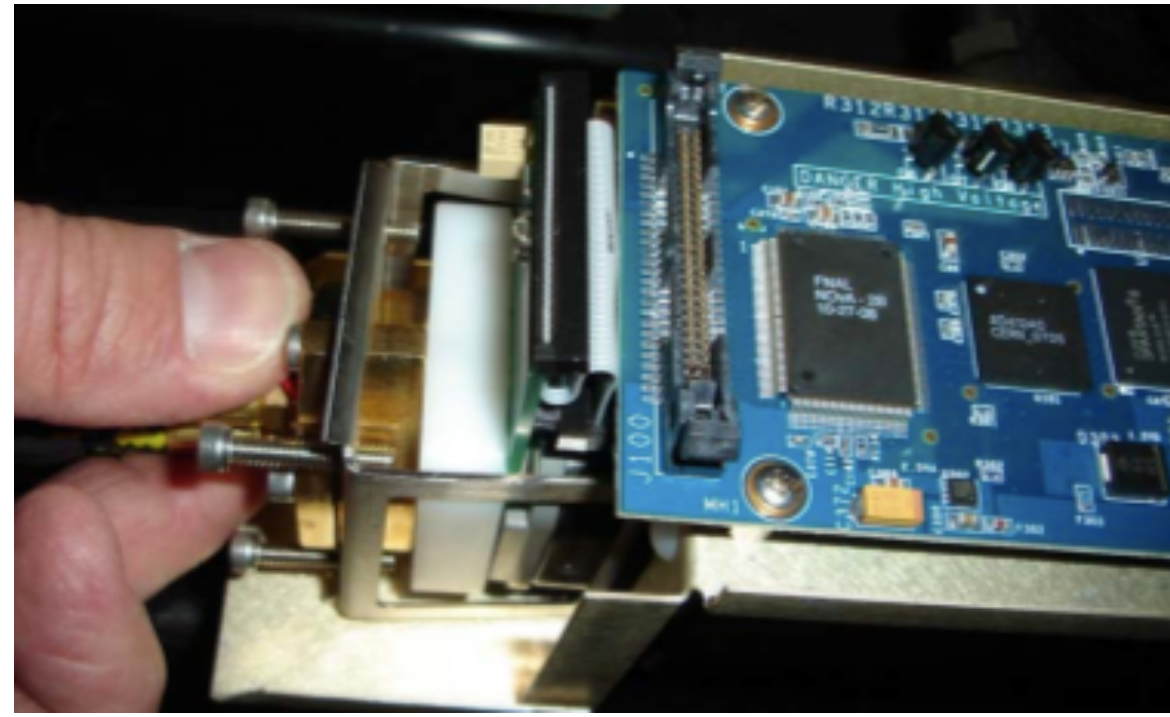
- Only 80% of the APD boards installed on NDOS function well enough to be used in the readout. *No where near an acceptable rate for the experiment.*
- The quality of the installation work on the NDOS varied considerably. Many APD installations do not make a proper seal against the environment allowing moisture to reach the APD. These APDs run warm but not cold (-15^{o} C) and will be reinstalled.



APD and carrier board attached to spacer



APD attached to heat sink



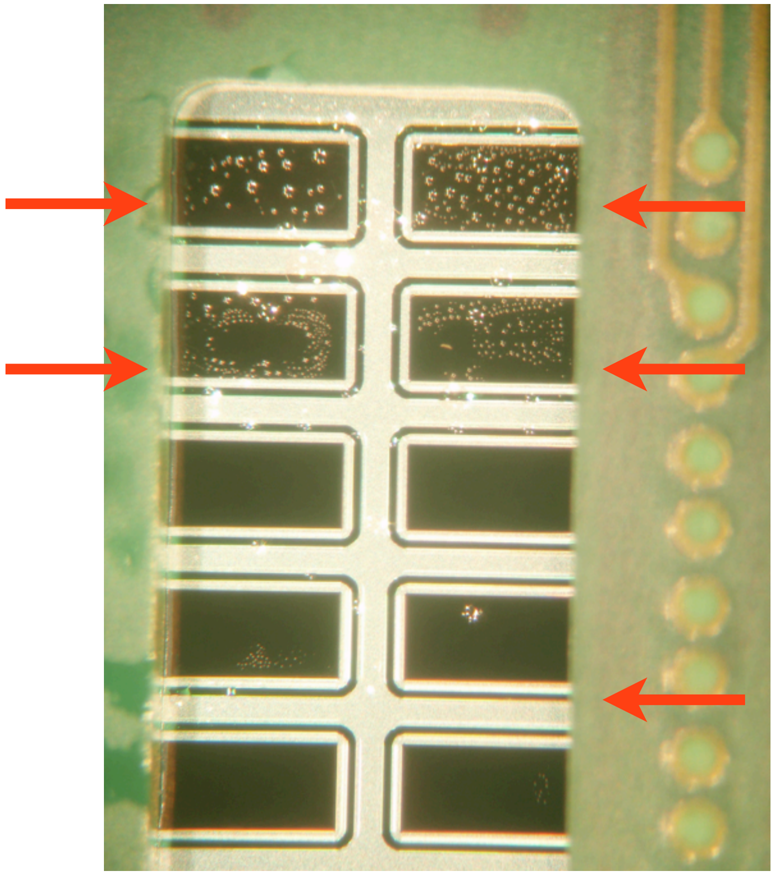
APD assembly attached to front end board which is preinstalled on the detector

APD installation

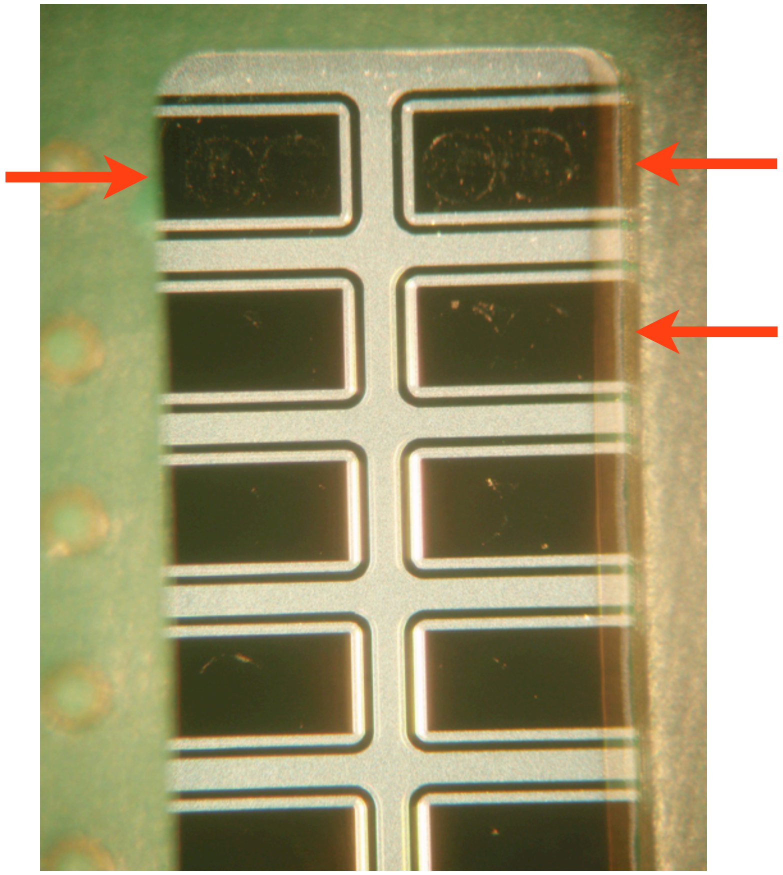
Lesson learned: APD installation

Examples of dirty APD faces

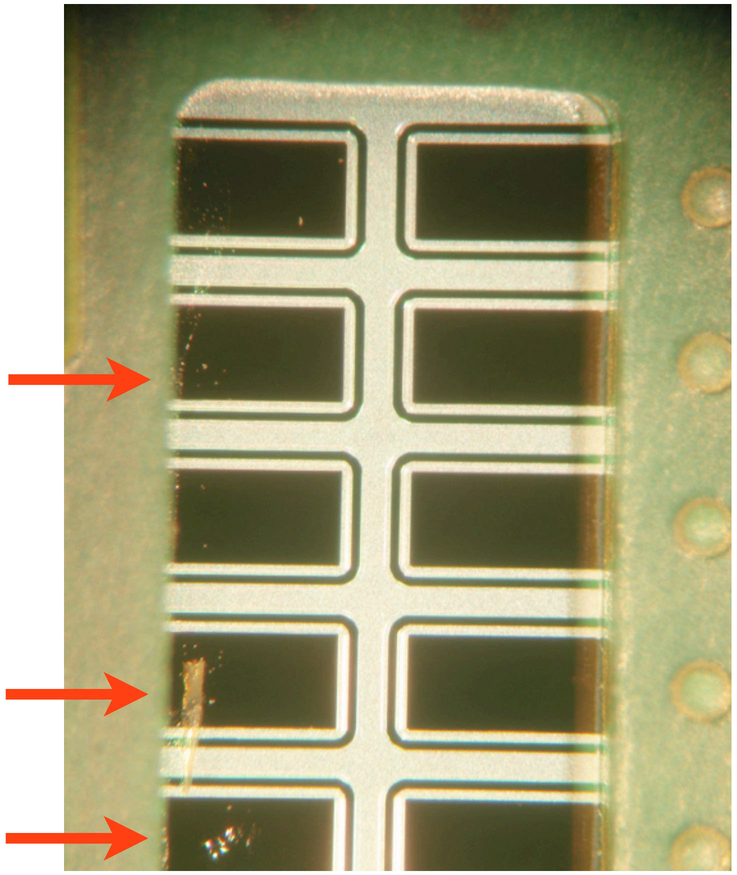
Scintillator on face



Fiber contact



"Dust"



Some relevant history

- Hamamatsu epoxy coats the silicon on its APDs but the standard epoxy coating was too thick to meet our requirements.
- Hamamatsu suggested we not use an epoxy coating and we had success with this in small quantities on test stands.
- However, under real detector conditions it is very difficult to keep the APD face clean.

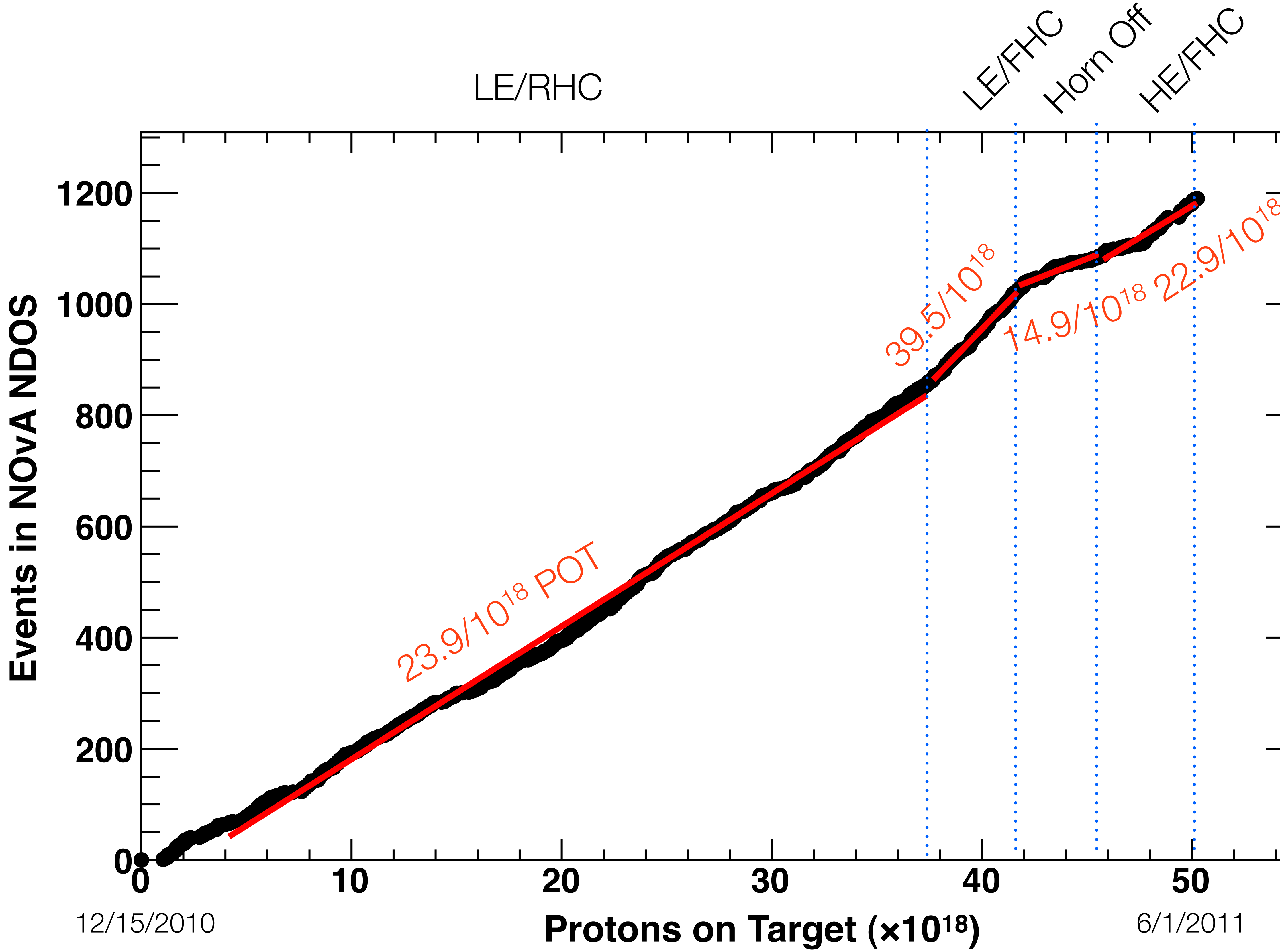
APD Installation:
The solution

Hamamatsu will epoxy coat the APDs to our specifications

- We've received dummy APDs from Hamamatsu with epoxy coating that meets our specifications.
- Expect to receive first functioning epoxy-coated APDs in 7 months. Asked for quote on samples using two different epoxy coatings (250 of each kind) to arrive in time for testing on NDOS.
- Cost is reasonable: $350/part uncoated, $372/part coated.

Best practices learned at NDOS will be codified and applied to near and far detectors by trained technicians.

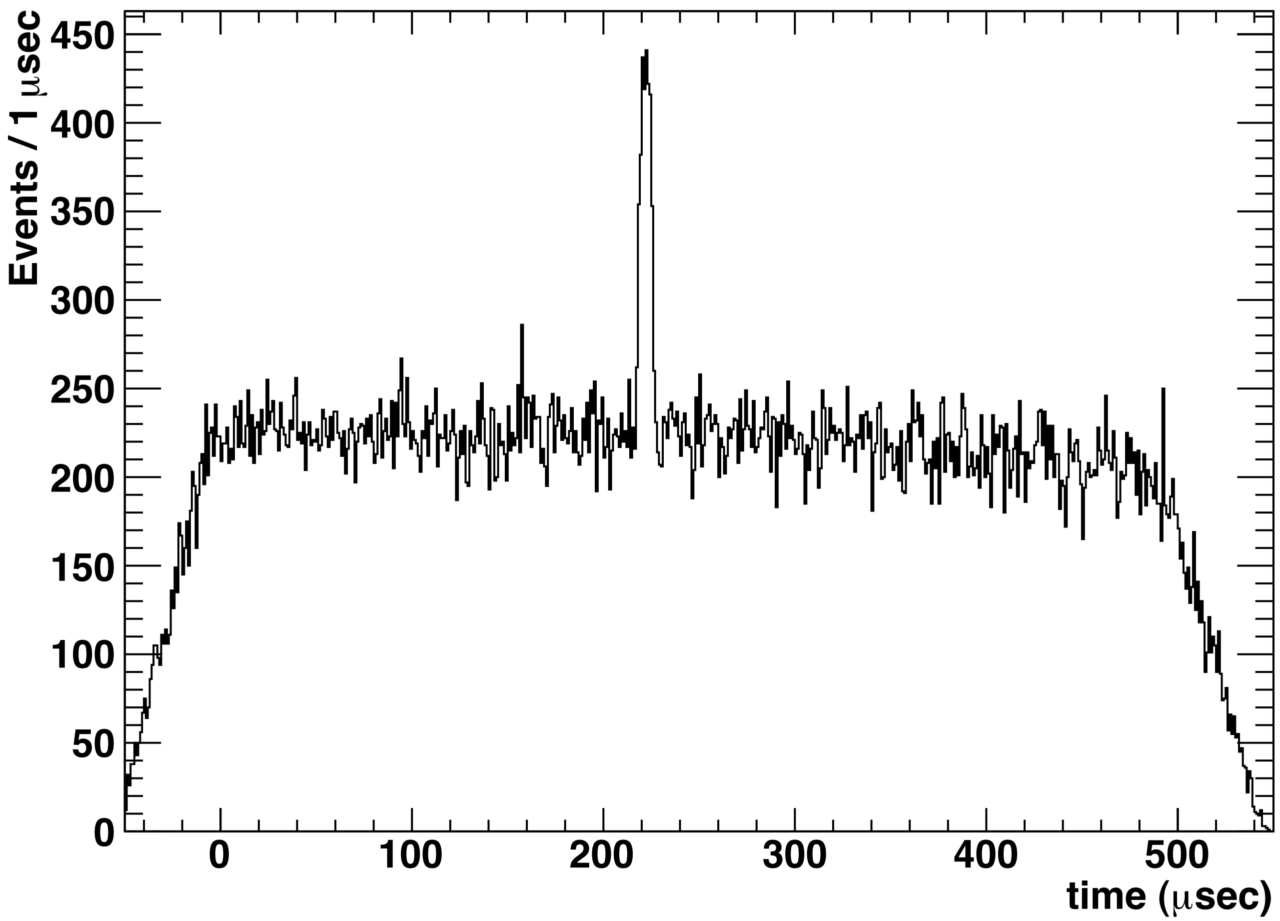
- Using the best practices learned on the NDOS we have roughly 95% success rate installing the uncoated APDs. Consistent application of these best practices coupled with the epoxy coating should get us to very close 100% success rate.

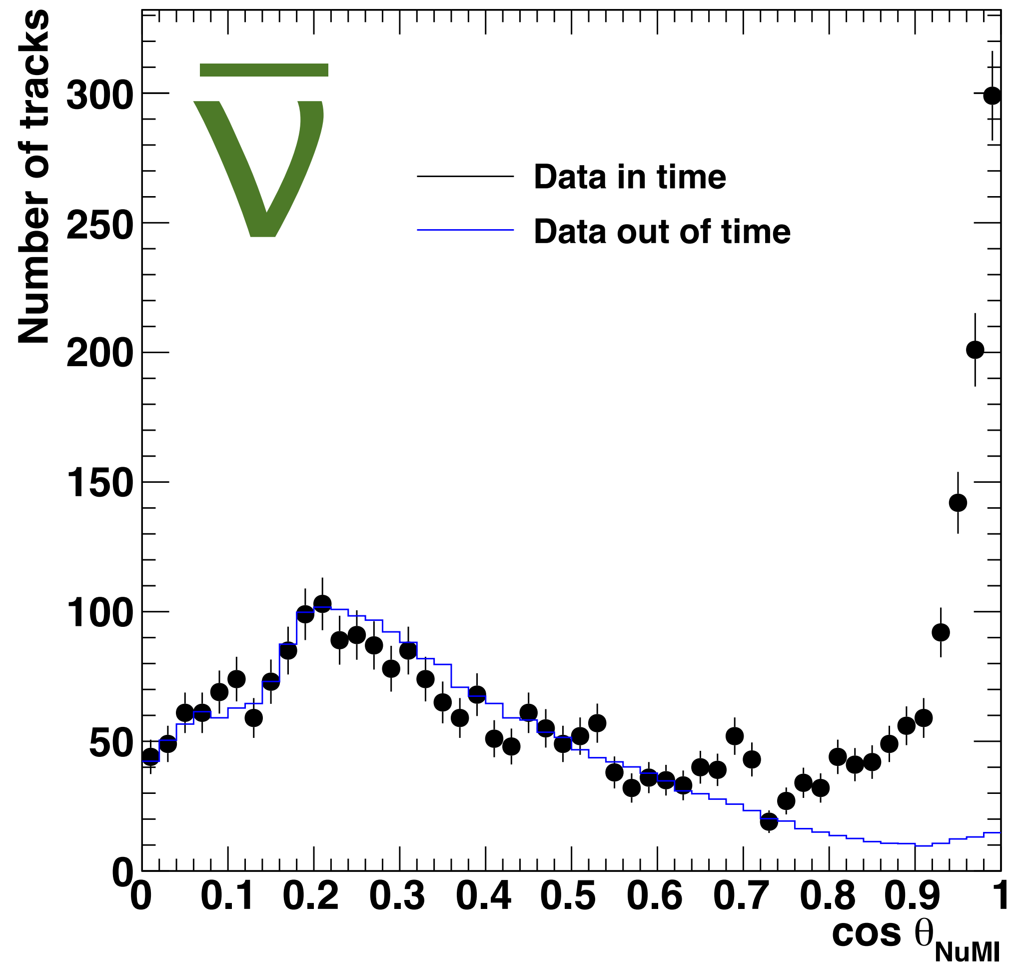


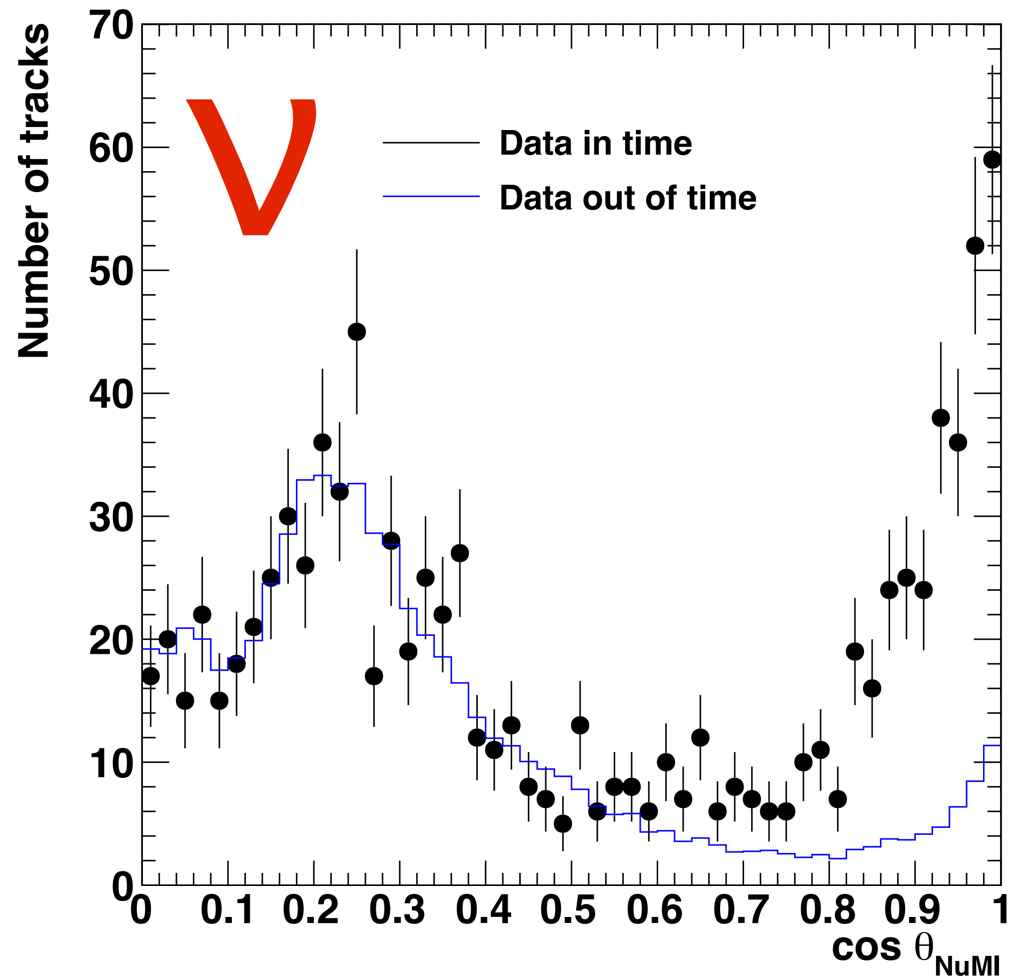
NuMI Events In NDOS

LE = Low Energy target position
HE = High Energy target position
RHC = Reverse horn current (antineutrinos)
FHC = Forward horn current (neutrinos)

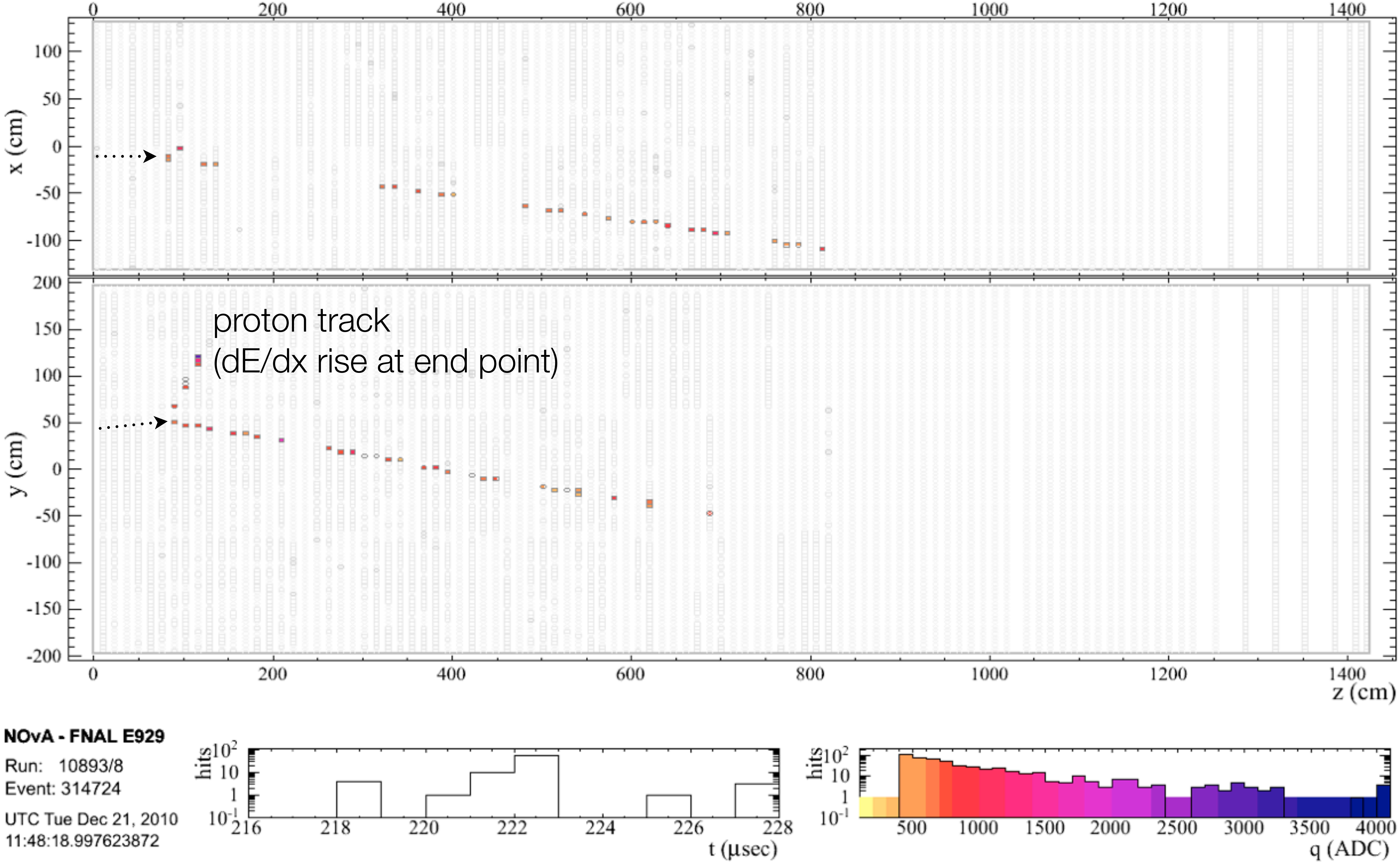
NuMI events





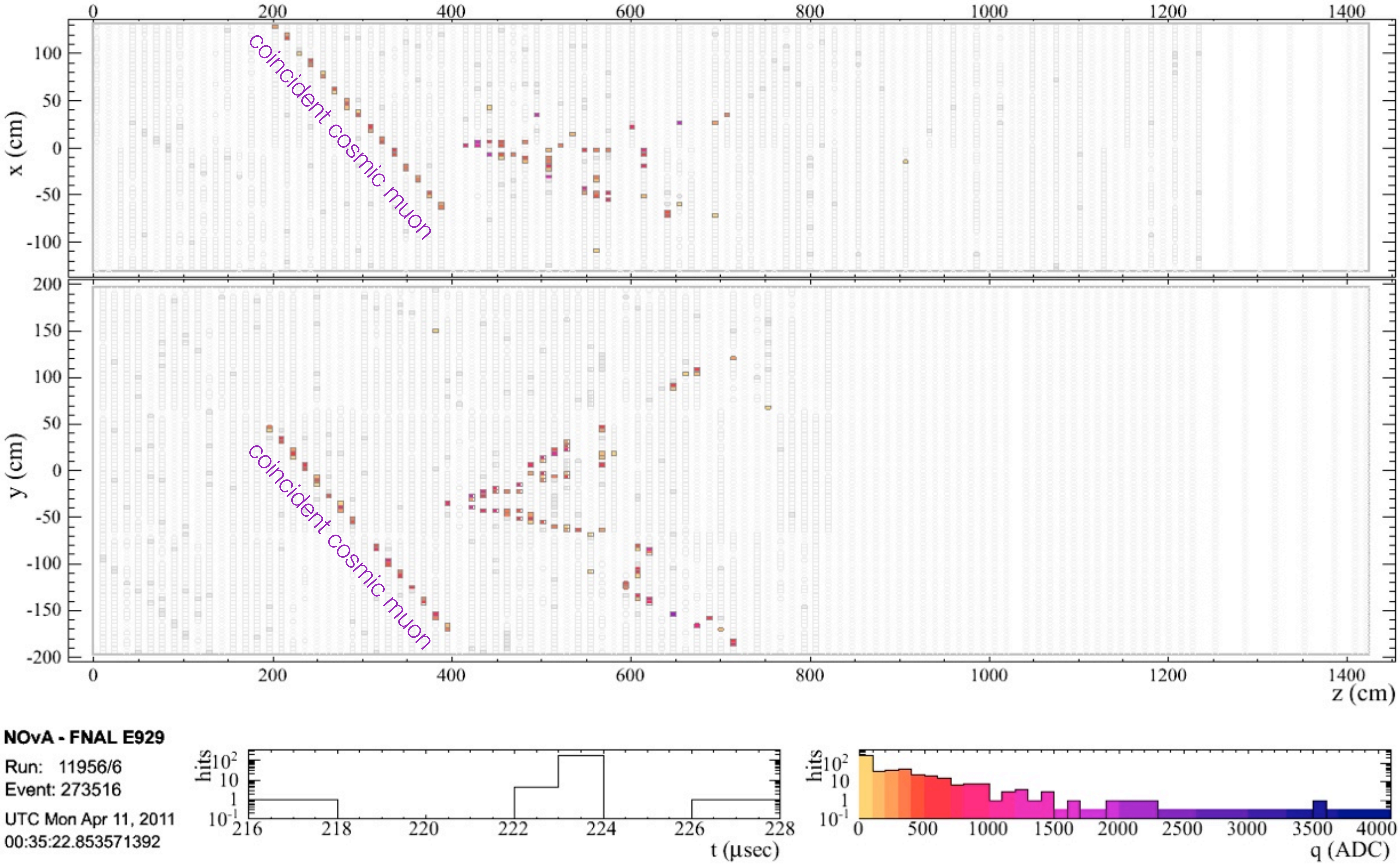


- See NuMI beam at off-axis angle of 110 mrad
- Recorded 1001 events in antineutrino mode (69 cosmic background)
- Recorded 253 events in neutrino mode (39 cosmic background)



NOvA NDOS NuMI Data

ν_μ quasi-elastic candidate

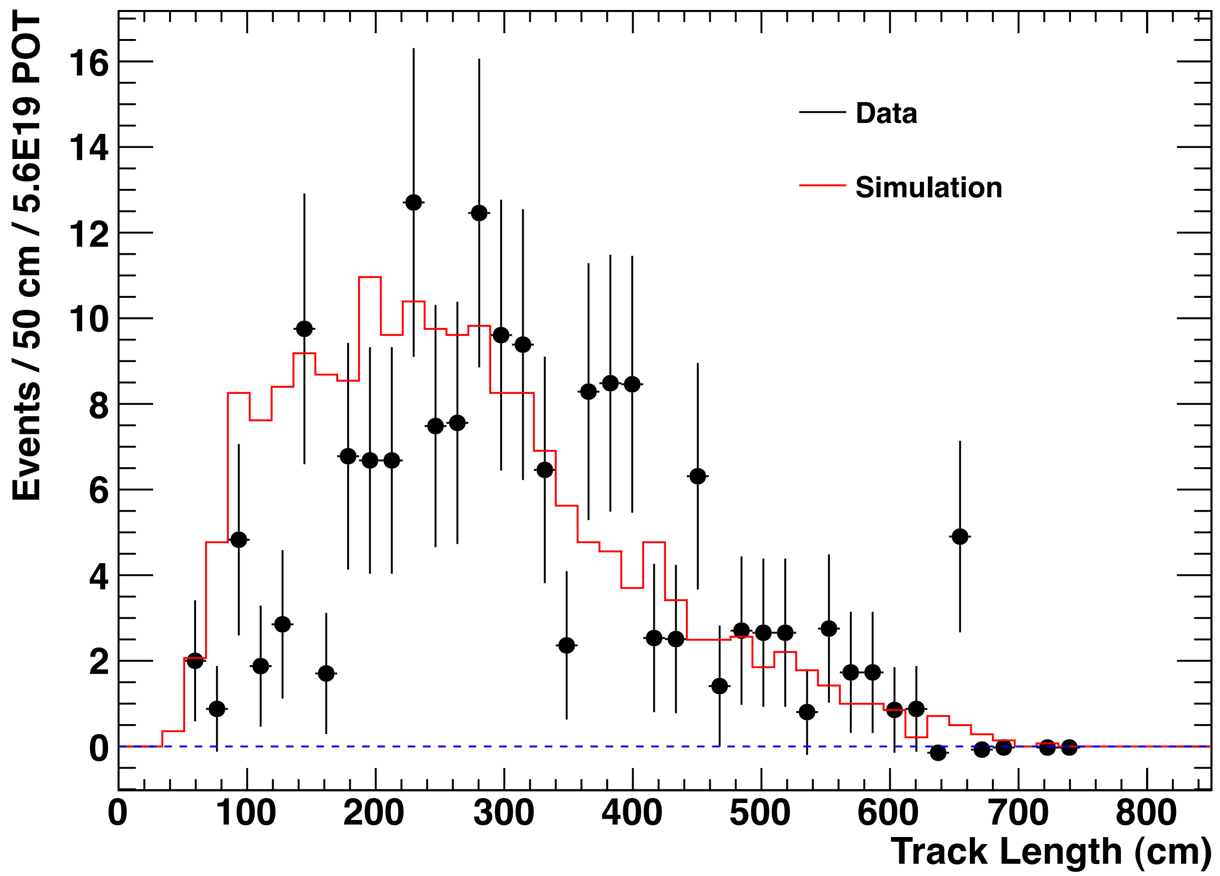


NOvA NDOS NuMI Data

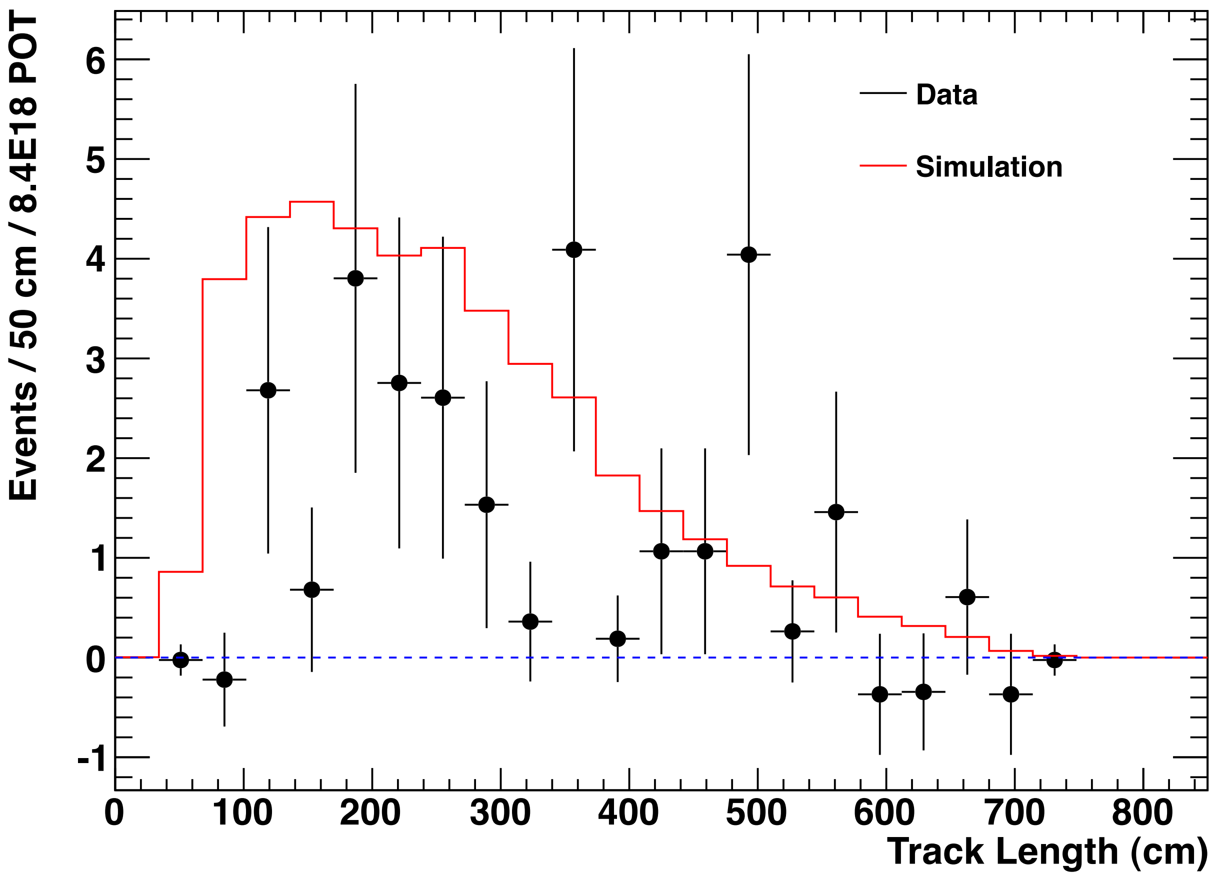
$\nu_\mu + N \rightarrow N' + \nu_\mu + \pi^0 + \pi^0$ candidate

NuMI neutrinos
Track length comparisons

antineutrino beam

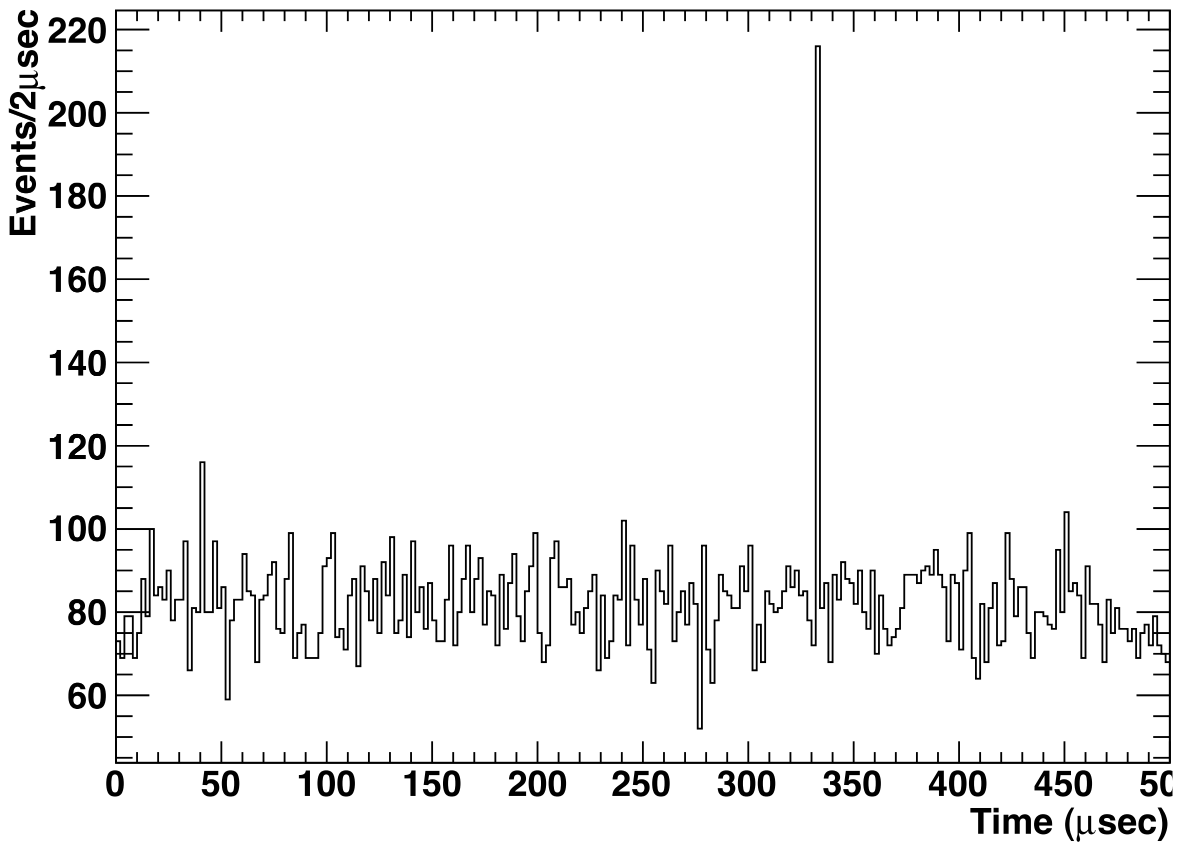


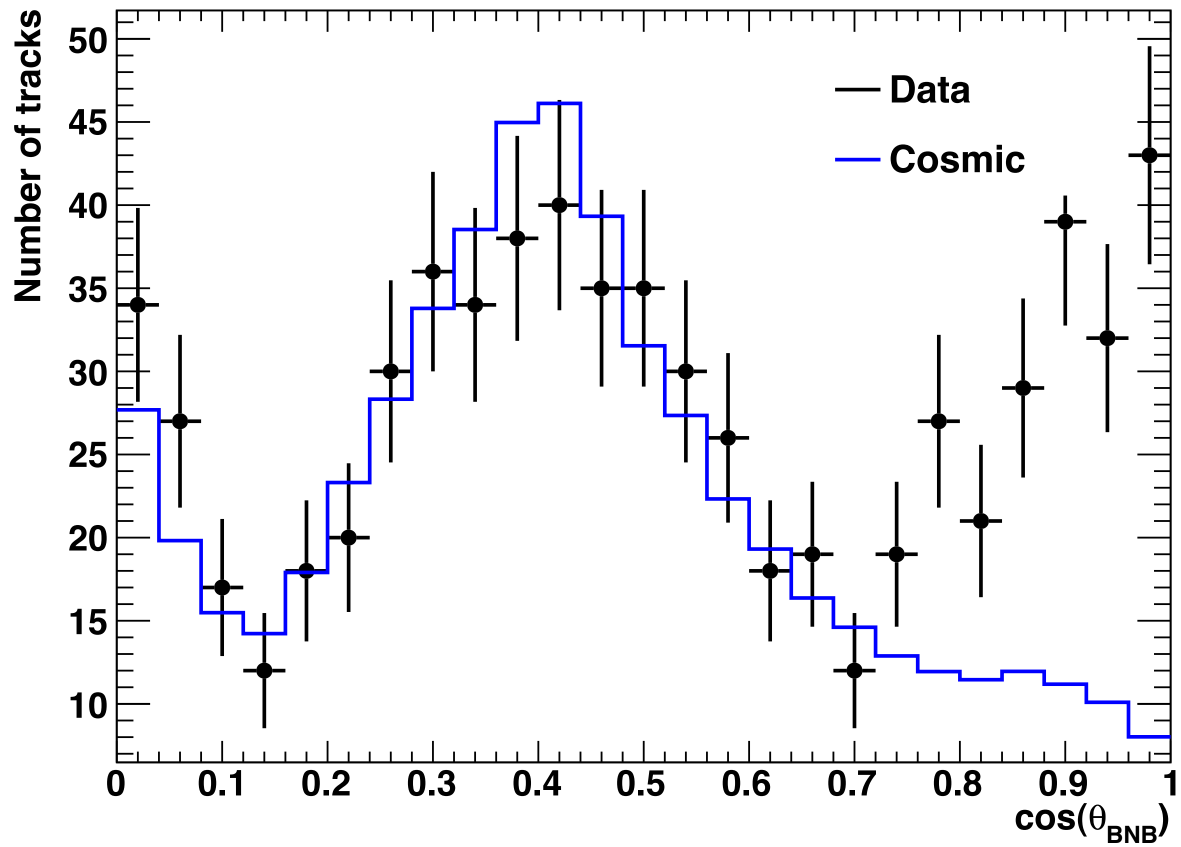
neutrino beam



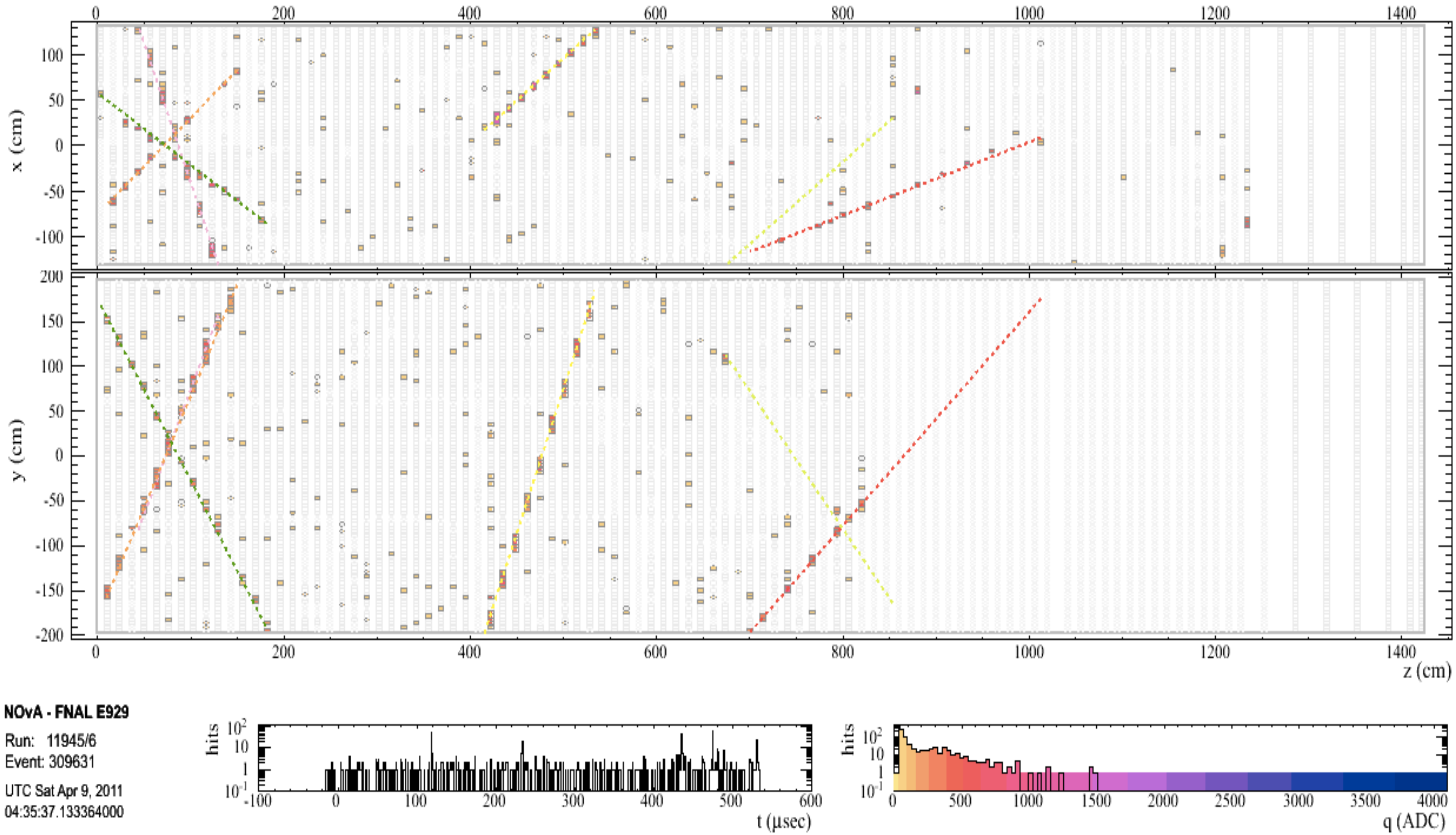
Comparisons of the track length distributions for fully-contained events in antineutrino (left) and neutrino (right) NuMI beam. Data and simulation are normalized to protons on target.

Booster Neutrino Beam



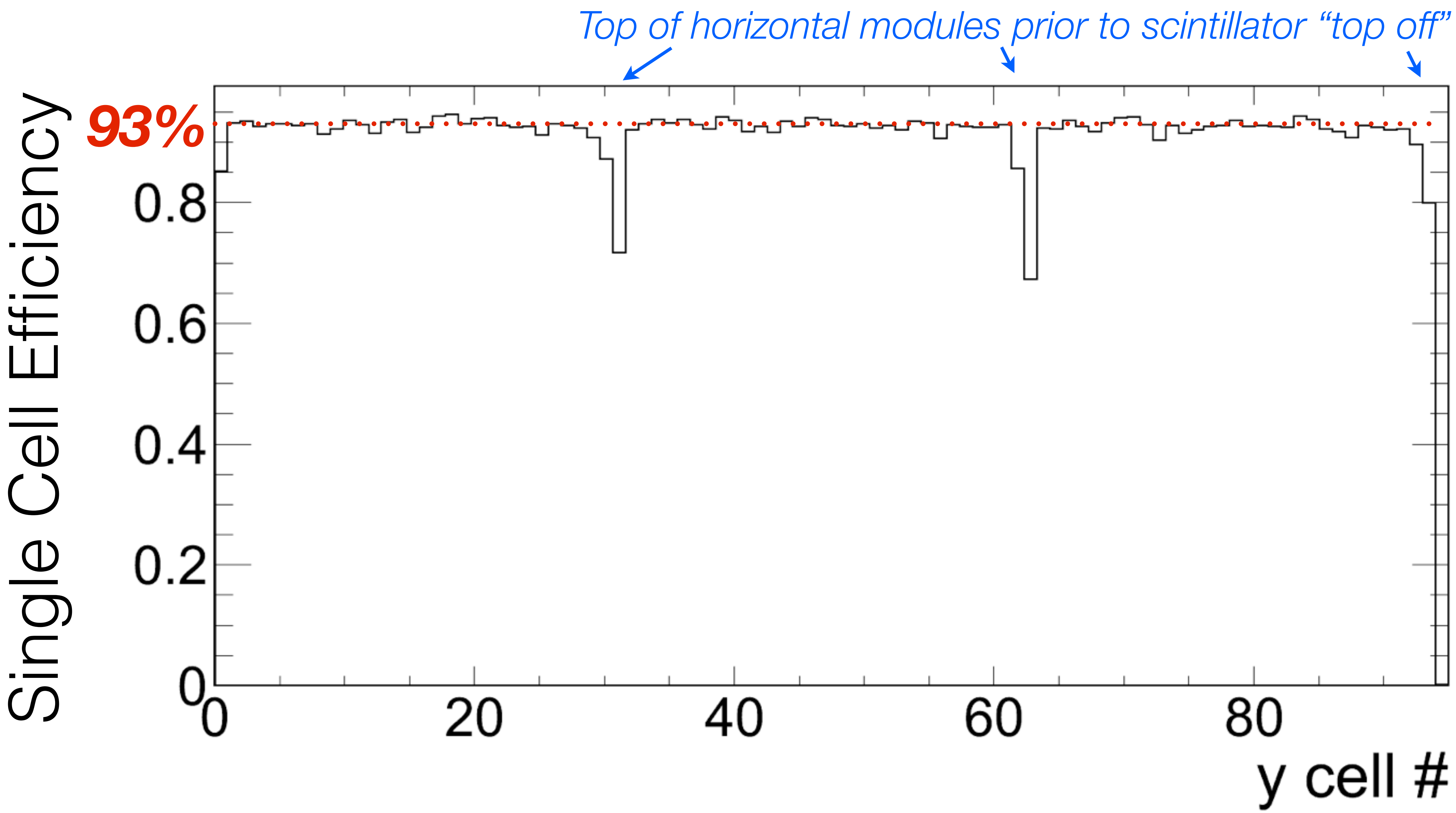


- NDOS is located on Booster Neutrino Beam (BNB) axis, rotated with respect to the beam by 23^{o}
- Recorded 2.7x10^{19} protons on target. First event recorded on 12/24/2010. Last event in this sample recorded on 5/22/2010.
- 222 events on a background of 92 cosmic ray backgrounds. 5 ν's / 10^{18} POT.



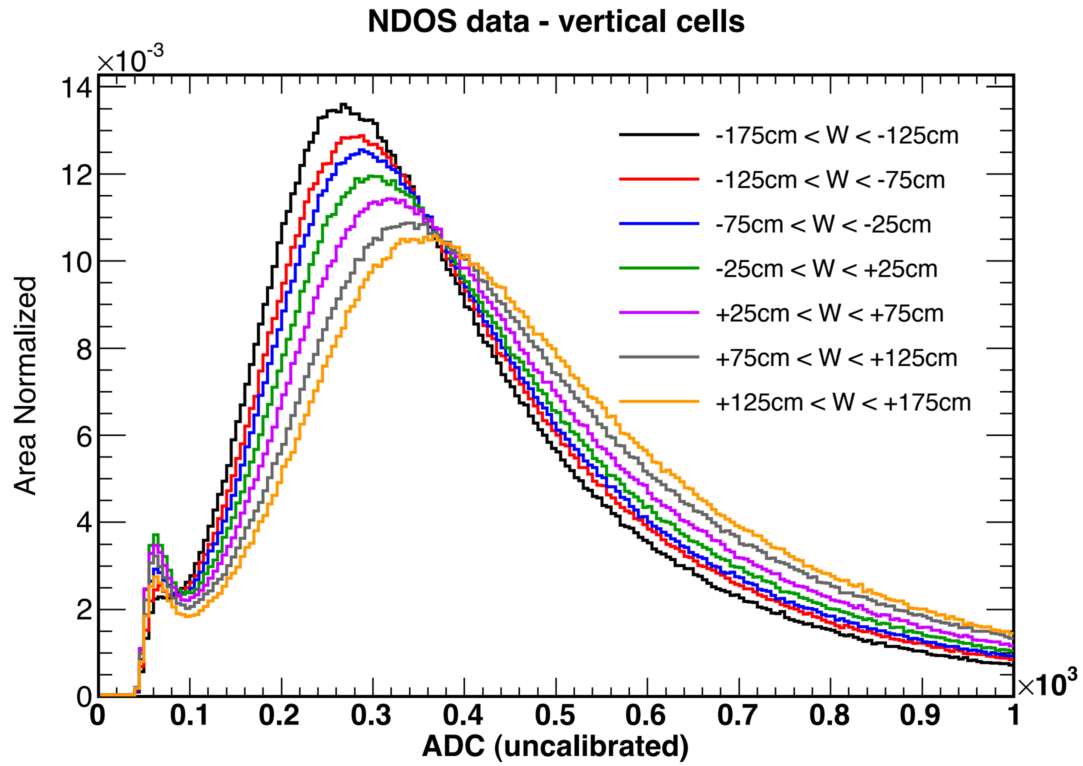
Cosmic rays in NDOS

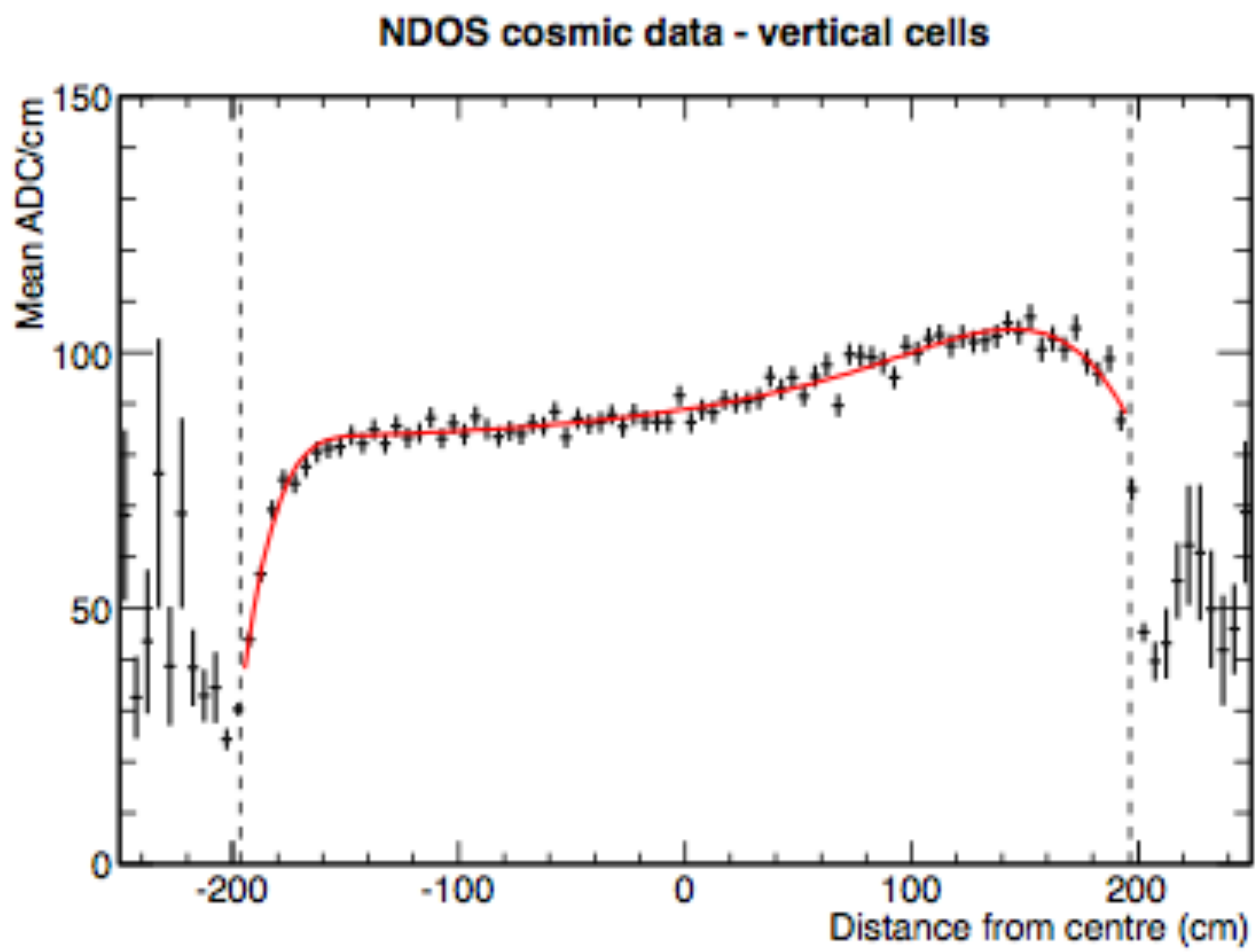
Using cosmic rays:
Cell-by-cell tracking efficiencies

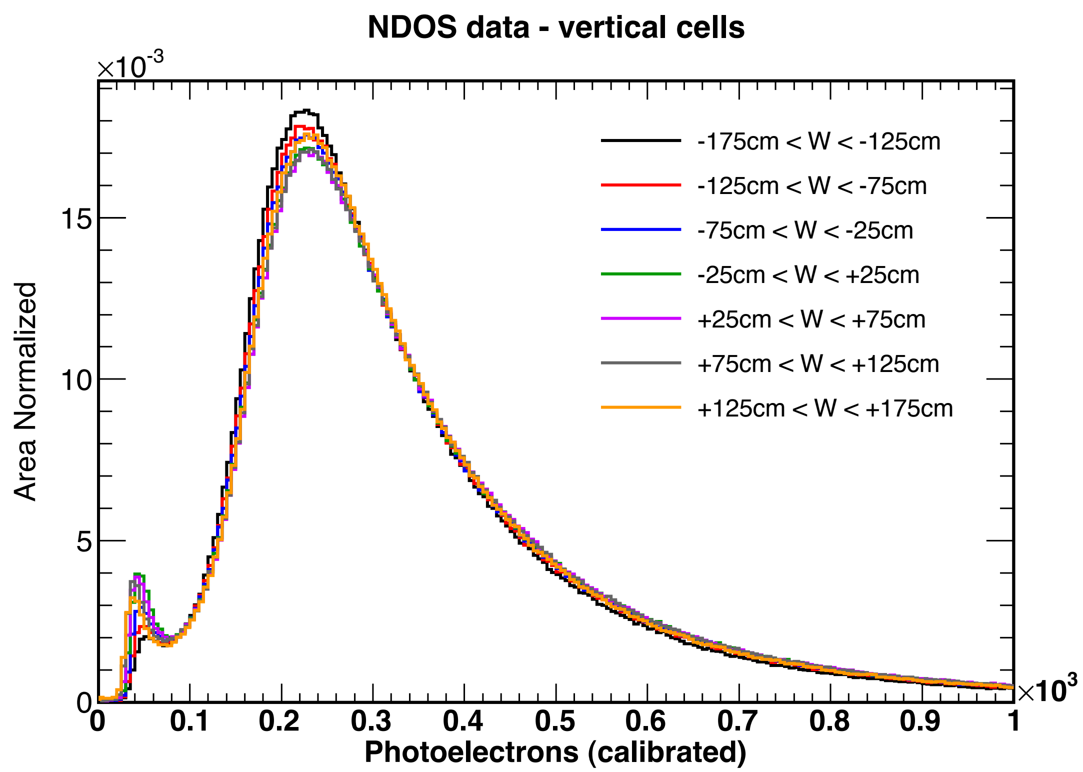


Note: Alignment still in progress. Likely to increase with alignment constants applied

Using cosmic rays: Cell-by-cell calibration

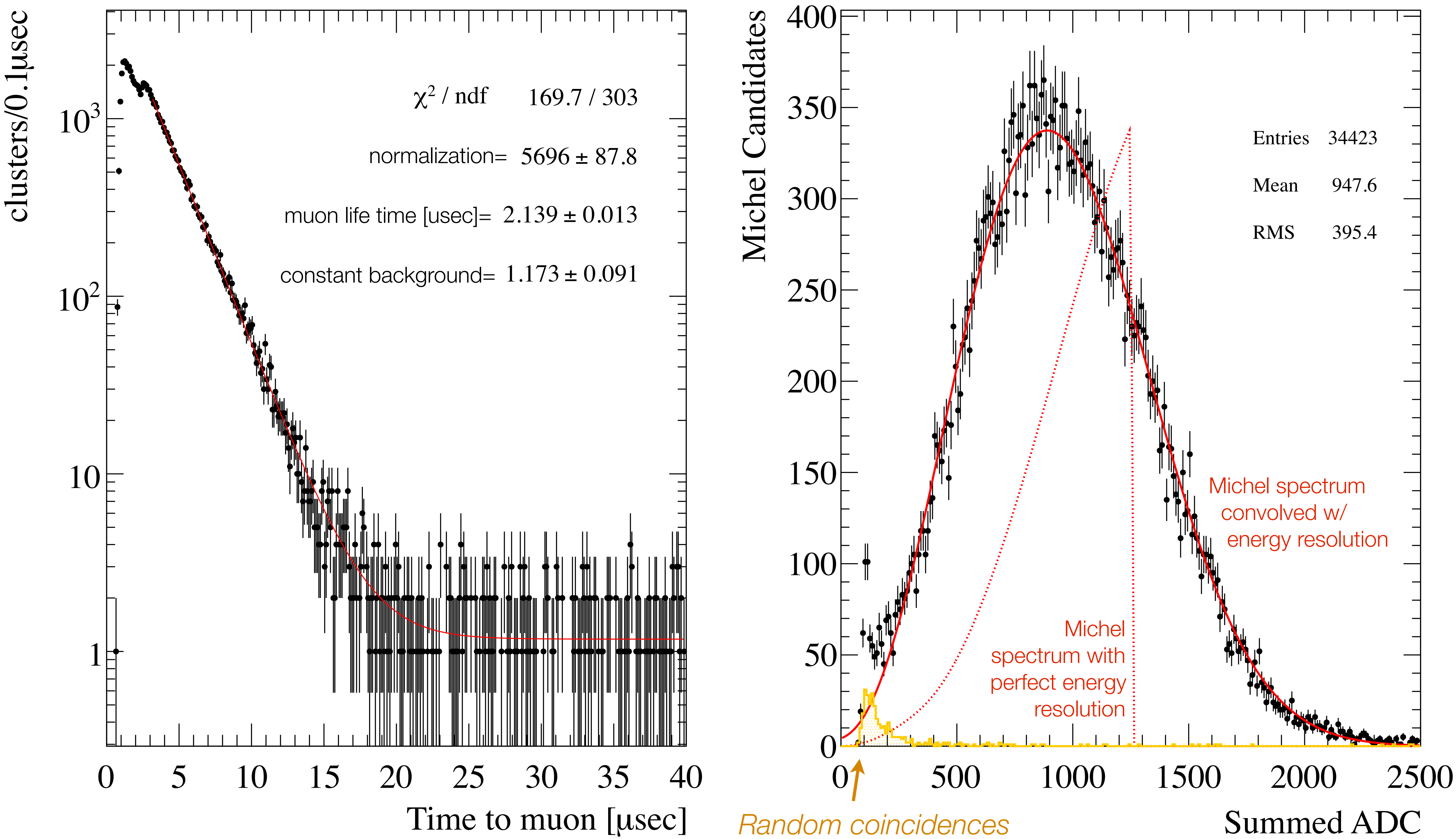






- Top left: Path length-corrected muon response for different distances from fiber end for a single example cell
- Above: Measured and fitted fiber attenuation for the example cell
- Bottom left: Muon response after attenuation corrections

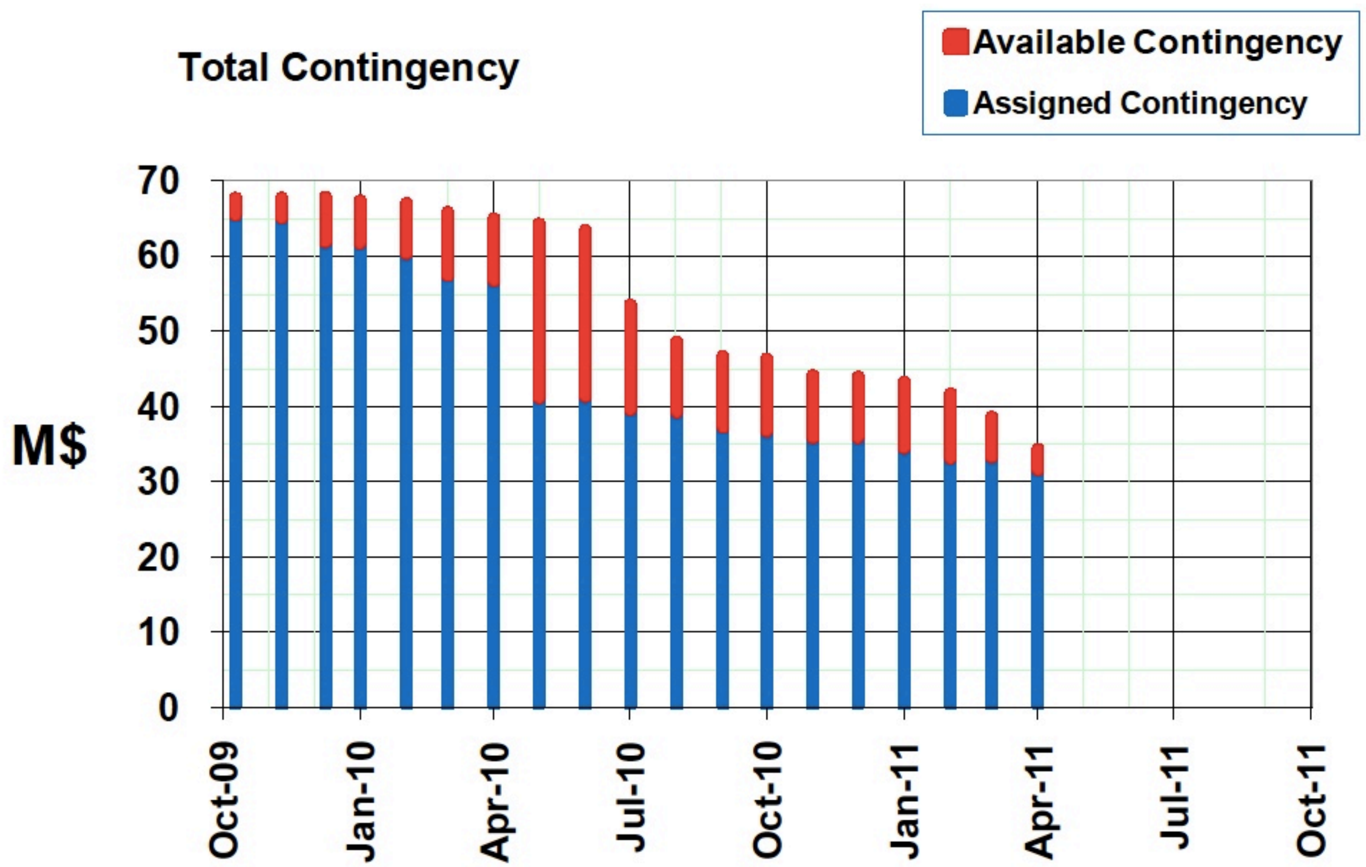
Using cosmic rays:
Michel electron calibration



Random coincidences
These are clusters that are matched to muons recorded 20 seconds prior to event

NOvA contingency

- The NOvA project is currently 70% obligated and 46% complete
- Available contingency has fluctuated from a high of $24M to a low of ~$5M
- Currently have $34M of contingency (26%)



- ***Available contingency is used first to reduce project risk and to hold or to advance the project schedule.***
- Any available contingency we may earn beyond that which is needed for the above could be applied to other things.
-

Ideas for contingency use

- We are authorized to build up to 18 kt of detector and could continue to add mass until all available contingency is spent. To reach 18 kt would require ~$30M and would require us to know we had the contingency earned far enough in advance to keep the supply and production lines going and not jeopardize CD4 milestones.

- Project management thinks its possible that we may generate ~$15M in contingency by end of project, enough to reach a far detector mass of ~16 kt

- Once we reach a steady state building far detector blocks we will either be using or earning contingency at a steady rate. This will allow us to look ahead and see how much contingency we expect to end the project with.

- We think there are ideas for contingency use that can increase the science reach of the experiment more than a $\sqrt{(16/14)}$ = 7% increase in statistics.

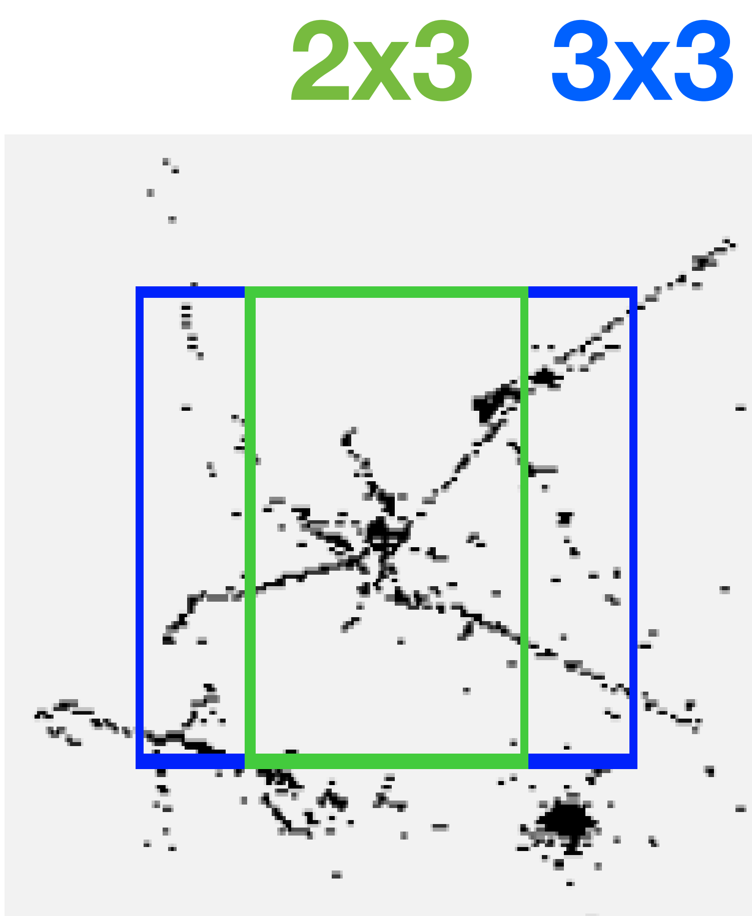
Ideas for NOvA contingency use

	Summary	Cost	Status
Rebuild near detector	Rebuild the near detector to match the far detector geometry and apply lessons learned from prototype detector.	\$5M	Need to do this.
Test beam module	Construct a small NOvA test beam module to measure response to $e/\pi/\mu$ in a test beam.	\$<1M	No concrete plans yet, but small enough that it could happen on the margins of far detector.
Additional far detector mass	Add 16th, 17th, 18th kiloton to the far detector. Improves statistics but not systematics.	\$9M/kt	Some procurements made toward 18 kt, but may prove difficult to orchestrate.
Wider near detector	A wider near detector will improve containment of EM showers and π^0 events and sample a large range of off-axis angles allowing in situ studies of neutrino flux extrapolation. Incurs some excavation risk as pillar separating NOvA and MINOS halls is stressed.	\$2-3M	Under study. Proceeding with cavern designs.
SciNOvA	A 15 ton fine grained detector to be placed in front of NOvA. Would allow for in situ studies of backgrounds and cross-section measurements at 2 GeV.	~\$3M	Joint study group formed NOvA/SciNOvA
Additional cavern further off-axis	A new cavern to house the current prototype. The cavern would access off-axis angles of up to 24 mrad where the neutrino spectrum peaks at 1.5 GeV. Could allow for study of oscillations at L/E ~= 1 km/GeV using fixed L and varying E as well as cross-section studies in the 1-2 GeV range.	~\$3M	Under study. Proceeding with cavern designs.
2 km detector	***Not being considers as part of the NOvA project*** but rather a new experiment to study the LSND effect. A microBooNE-style detector placed in NuMI at ~2 km + Project-X can cover the whole LSND range at 5σ.	\$30+M	Presented at short baseline workshop

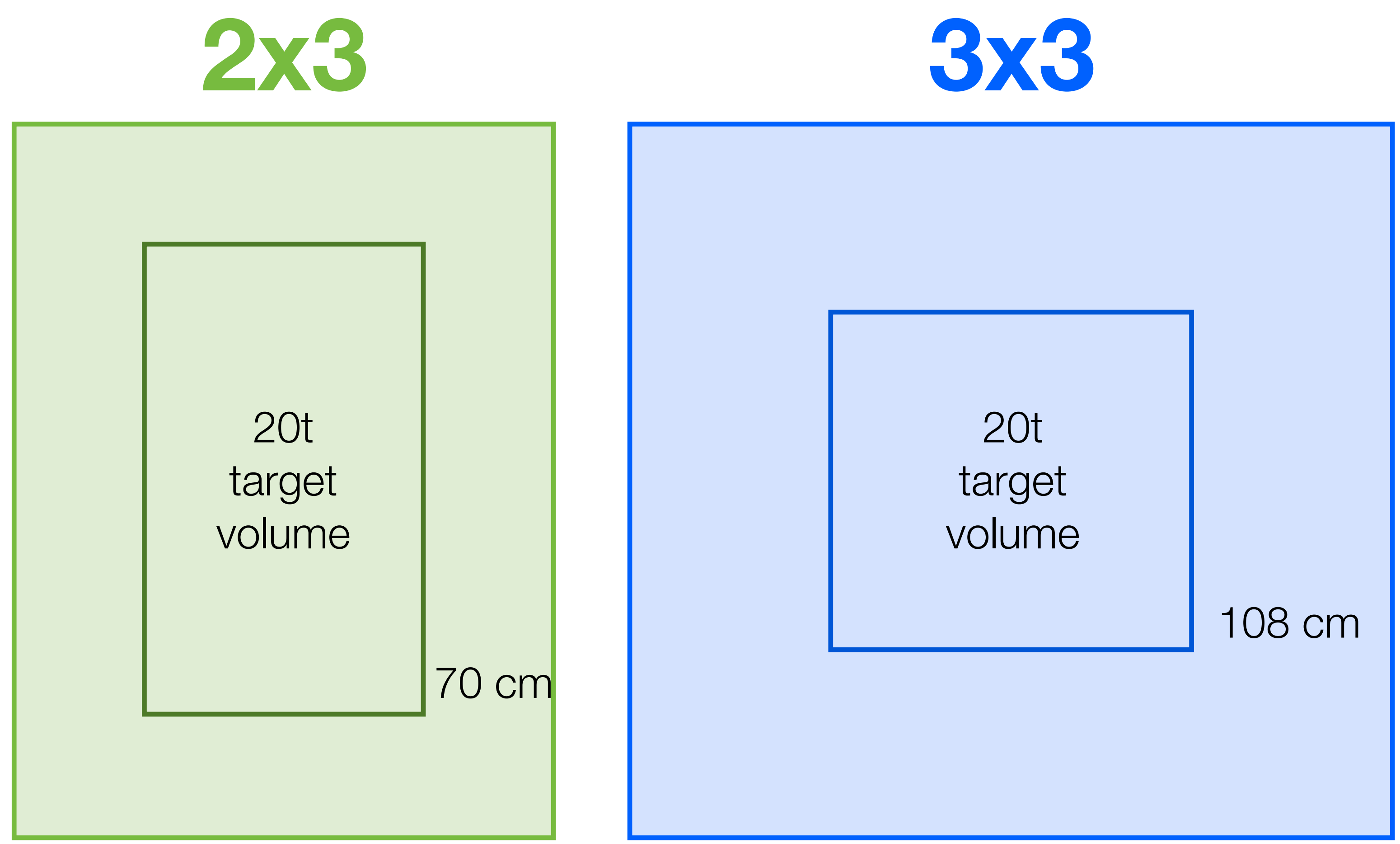
Wider near detector

- The main role of the near detector (ND) is to measure backgrounds to the electron neutrino appearance search so that they can be extrapolated to the far detector.
- The planned ND is 2 modules wide by 3 modules high (2.9 m x 4.1 m) and leaves 70 cm from the edges of the fiducial volume
  - The buffer is too small to fully contain all events; most events will have particles which exit the detector.
  - Ultimately, we will rely on Monte Carlo to correct, with some uncertainty, for the effects of non-contained events
- A larger near detector would also allow for improved studies of the beam extrapolation to the far site.
- Wider detector requires a wider cavern which incurs some risk

Wider near detector: Event containment



An example neutrino event centered on 2x3 and 3x3 near detector profiles

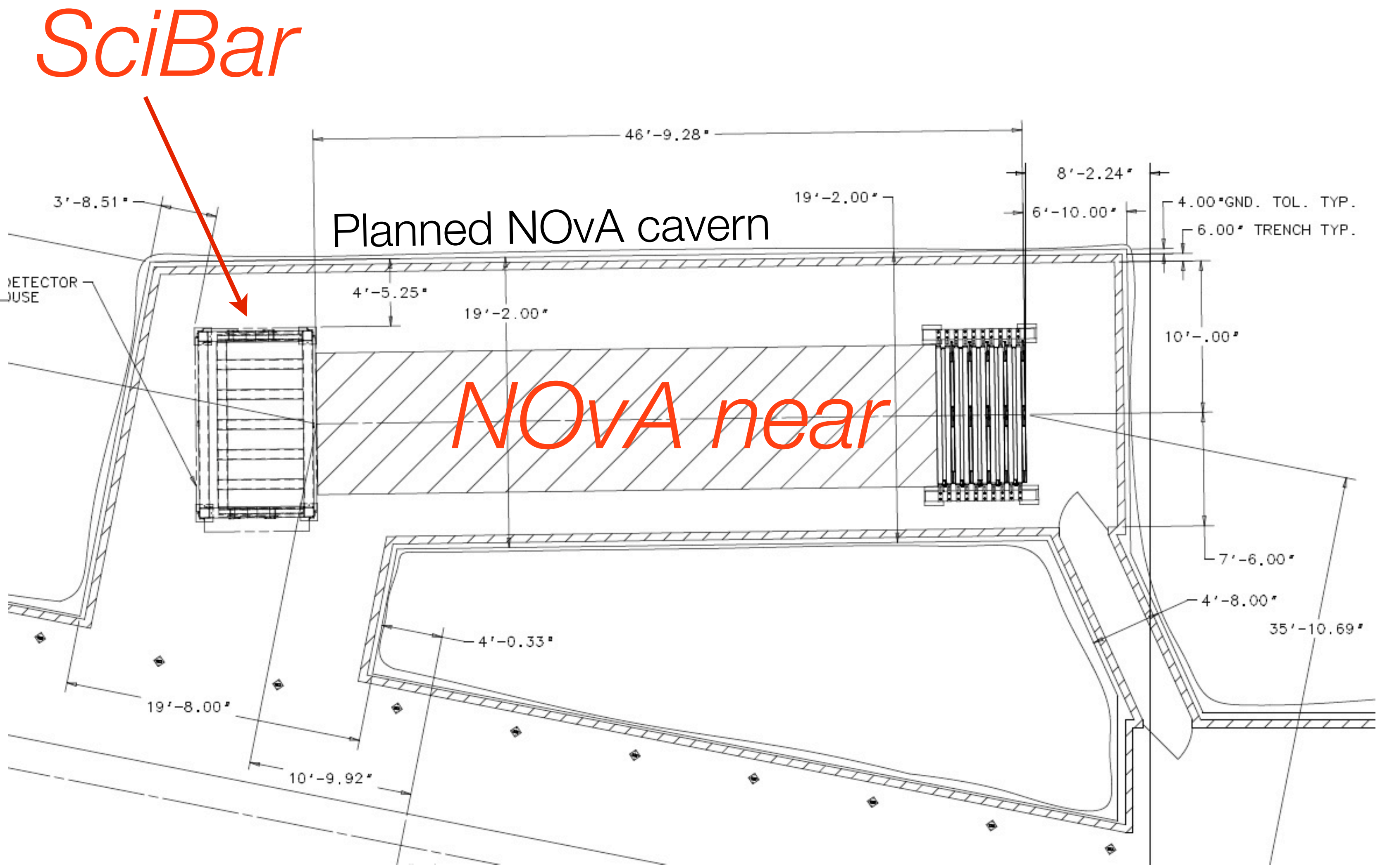


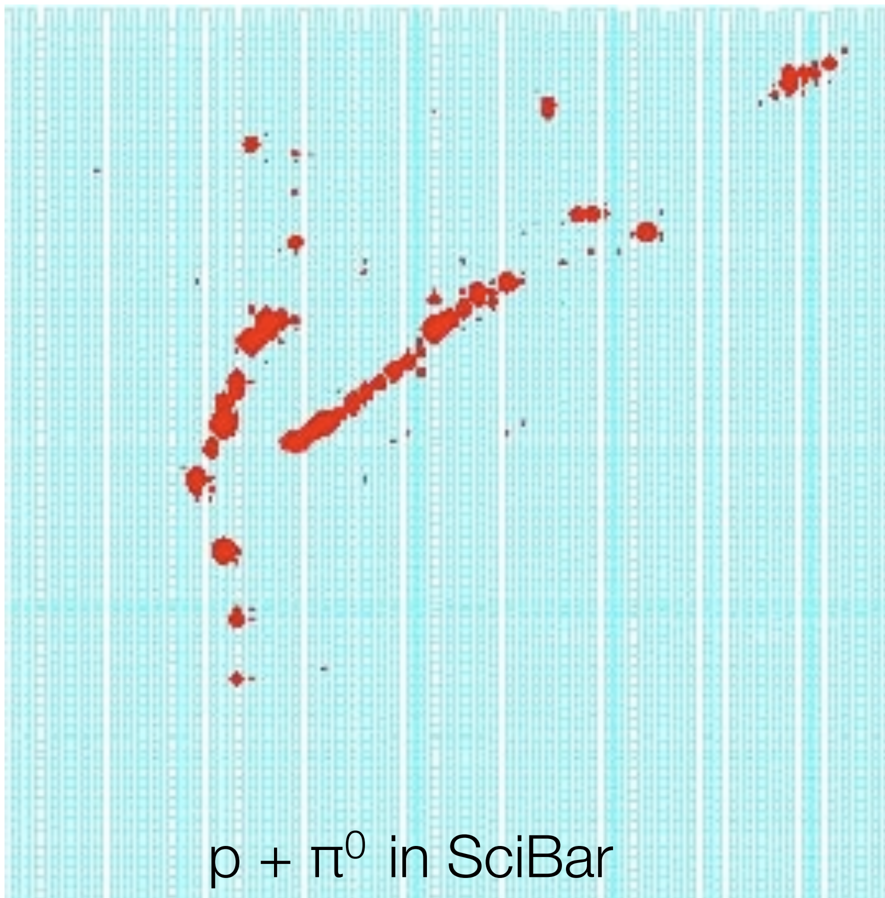
Detector front views

	2x3	3x3
Fraction of ν_e events which are 95% contained or better	61%	95%
Fraction of NC π^0 events which are 95% contained or better	44%	90%

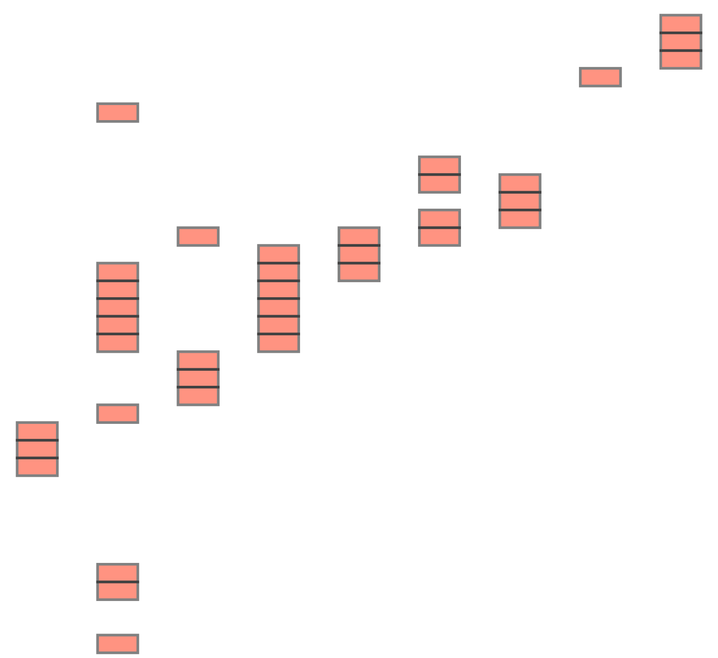
SciNOvA

- SciNOvA is an idea to rebuild the SciBar detector used by K2K and SciBooNE and deploy it in front of NOvA near detector.
- Main motivation is to allow an in situ check of NOvA backgrounds by sampling the same beam using very similar target material, but with higher granularity. Can nearly eliminate the need for Monte Carlo estimates of instrumental background rates.
- Also enables cross-section measurements in a narrow band beam at 2 GeV





p + π^0 in SciBar



Same event resampled in NOvA

SciNOvA

- In consultation with the NOvA executive committee, I formed a SciNOvA study group on May 16th comprised of NOvA and non-NOvA scientists.
  - Initial members:
    - Rex Tayloe - non-NOvA chair
    - Sam Zeller - non-NOvA
    - Rick Tesarek - NOvA
    - Jeff Nelson - NOvA
  - New members:
    - Sanjib Mishra - NOvA
    - Roberto Petti - non-NOvA
- This group has been meeting regularly on Mondays
- Basic charge is to work through the specifics of undertaking SciNOvA as part of the NOvA experiment

From: Mark Messier <messier@indiana.edu>
Subject: **SciNOvA Study Group**
Date: May 16, 2011 2:16:11 PM CDT
To: Rex Tayloe <rtayloe@INDIANA.EDU>, Geralyn Zeller <gzeller@fnal.gov>, Jeff Nelson <jkn@fnal.gov>, Richard Tesarek <tesarek@fnal.gov>
Cc: nova_execcom@fnal.gov, scinova@fnal.gov

Dear Rex, Sam, Jeff, and Rick,

As I've discussed with each of you individually, I would like to form a SciNOvA study group to continue to flesh out the plans for incorporating a fine grained detector into the NOvA near detector. I've asked Rex Tayloe to chair this study group.

The initial list of issues I would like the study group to address are:

1. Photo detector technology choice: SciBar and SciBath use M64s; NOvA uses APDs. T2K and groups at FNAL use SiPMs. What are the issues related to the photo detector technology choice and which is recommended for SciNOvA?

2. Scintillator extrusion shape: SciBar originally used rectangular bars 1.3 x 2.5 cm. Is this the best geometry for use by NOvA when scientific performance and practicality are considered?

3. Refinement of the construction and installation plans for SciNOvA. I would like the group to make progress toward a more complete cost and schedule, identify any long-lead items required for SciNOvA construction and identify any modifications required by SciNOvA to the NOvA near detector infrastructure and services.

I hope that an initial progress report on these issues could be made in time for the NOvA collaboration meeting to be held on June 27-29 with some final report by September.

Thank you for undertaking this work.

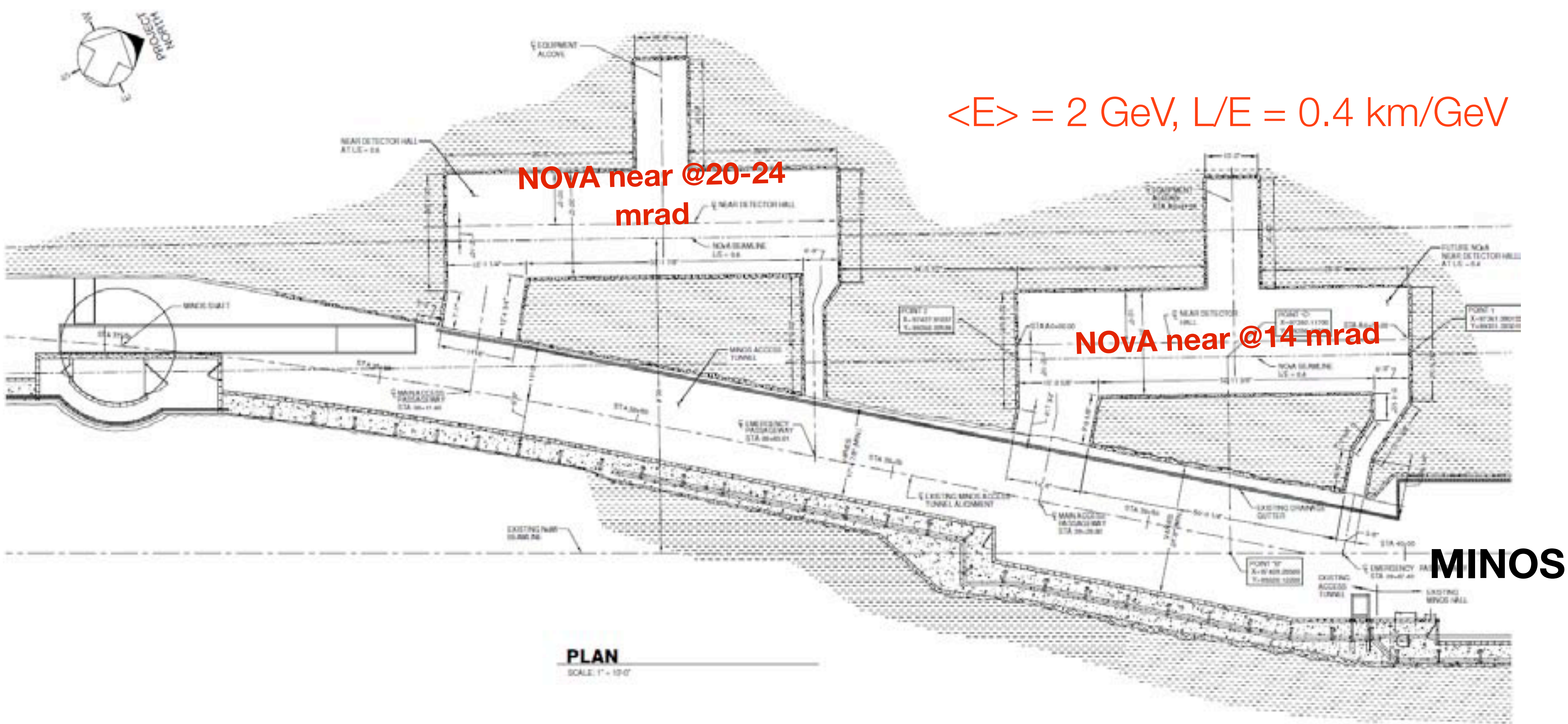
Cheers,
Mark

New cavern further off-axis

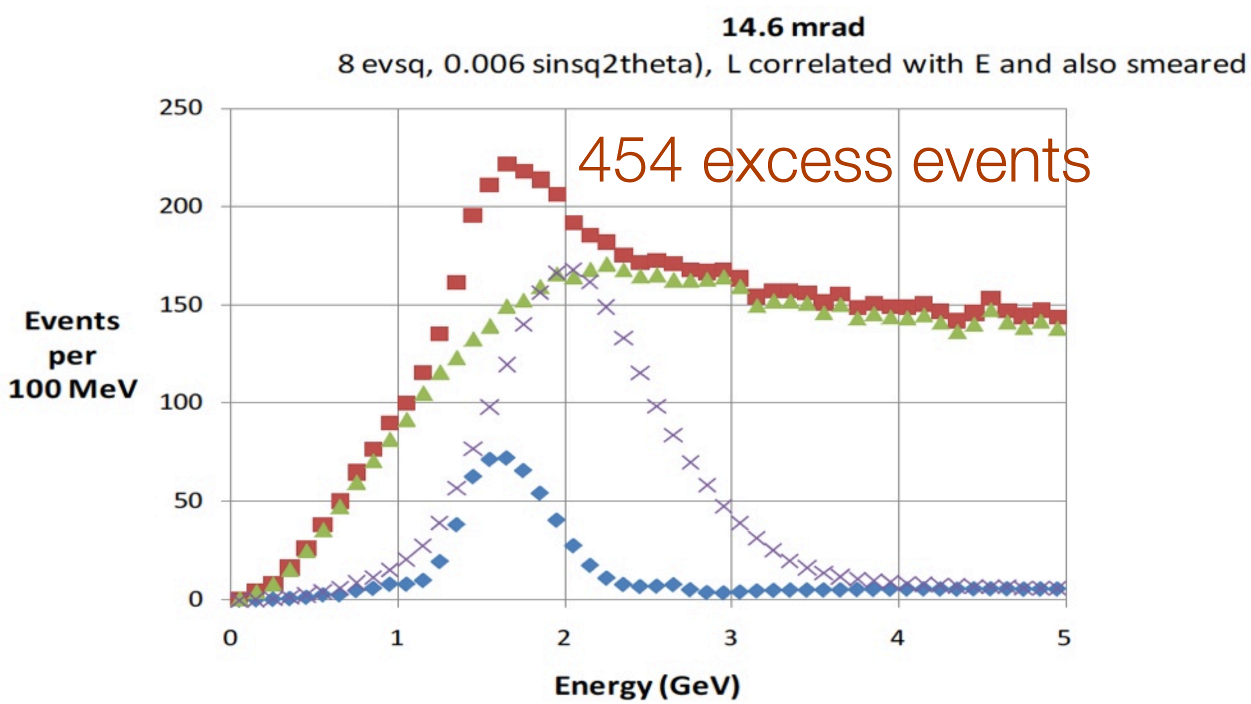
- If the MiniBooNE/LSND antineutrino signal is real and due to oscillations, those oscillations will develop downstream of the NOvA near detector
  - MiniBooNE/LSND signal is in the range of $0.4 < L/E < 1.2$ km/GeV
  - NOvA near detector is at $L/E = 0.4$ km/GeV.
  - Placing an additional NOvA near detector further off-axis (~24 mrad), reducing the beam energy to 1.5 GeV, NOvA can achieve an L/E of ~1 km/GeV
  - To get beam at 24 mrad would require a new cavern which could house the prototype detector we are now operating.
- Presented at Short Baseline workshop by John Cooper

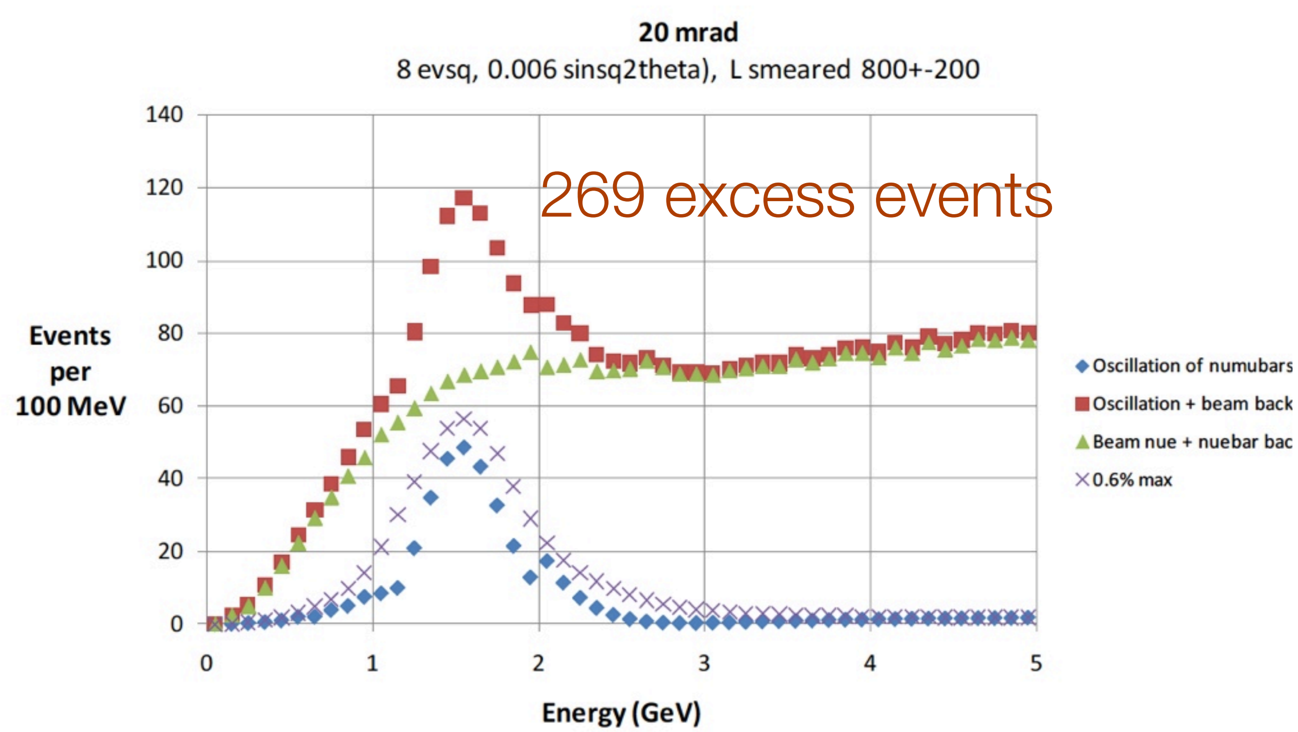
Possible new cavern at 24 mrad

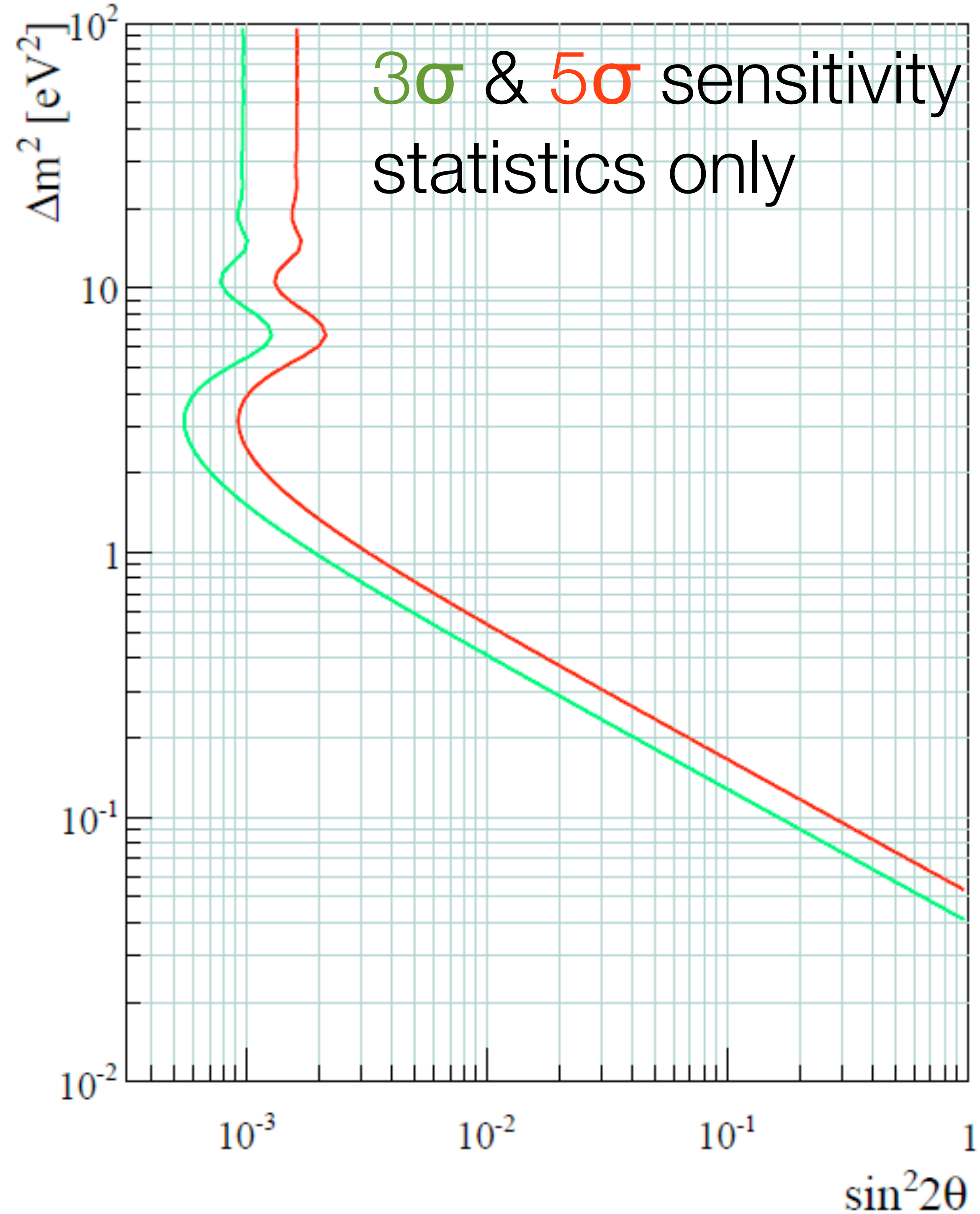
<E> = 1-1.5 GeV, L/E = 0.6 - 1 km/GeV



Possible signals in a new cavern







Summary

- The NOvA project is making good progress.
  - Ash River building and detector R&D are ~99/100% complete
  - Accelerator and NuMI upgrades are 45% complete
  - Far detector 26% complete
  - There is sufficient funding and contingency remaining.
  - Schedule has 5 months float to CD-4. Re-planing in progress to gain more.
- NDOS has provided an excellent opportunity to gain experience with NOvA construction, operation, and analysis well in advance of construction at Ash River.
  - Problems identified and corrected in advance of Ash River construction
  - Proving to be an excellent opportunity to train our students and post-docs with a real detector and real data.
- There are several plans under study to improve the performance of the near detector to enhance the scientific performance of the experiment. Time scale for decisions is next summer. In the mean time steps are being taken to keep options open.

Backup slides: Experiment progress

Experiment progress:

Far detector assembly area

Block assembly area

Experiment progress:

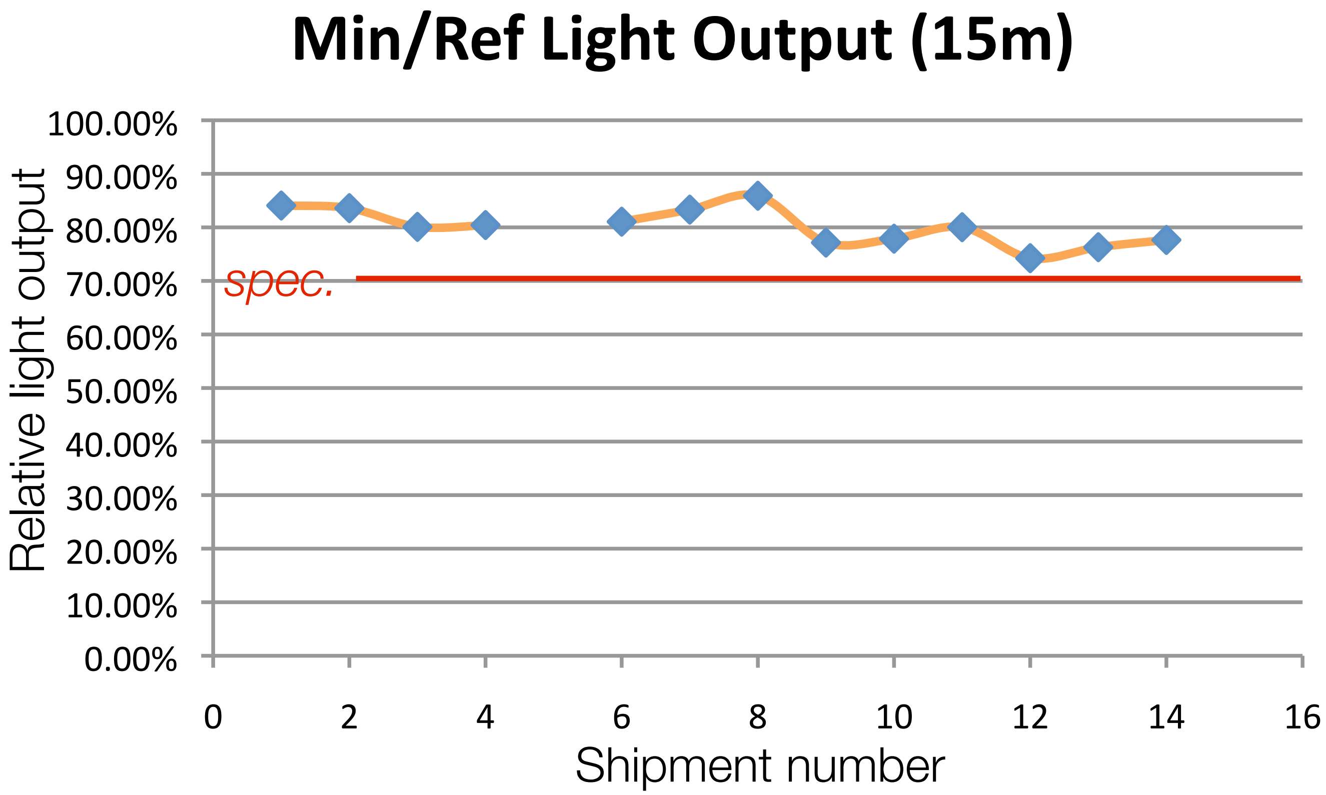
Scintillator and fiber

Scintillator

- **Mineral oil contract in place**
  - Have contract for fixed price for crude oil in range $60-$110 bbl, indexed outside this range. At $111 bbl price would be 22% higher than the fixed price; we continue to have 30% assigned contingency.
  - Taken delivery of first 164,000 gal of 3.2 million gallons required
- **Pseudocumene contract in place**
  - Price indexed to Asian naptha (crude oil)
  - 155,000 gallons required (22 ISO tanks)
- **Wave shifters in hand**
- **Blending PO has been issued**
  - Fixed price of $0.67/gal + $600K of setup
  - Test batch of 30,000 gallons blended and in use by near detector prototype

WLS fibers

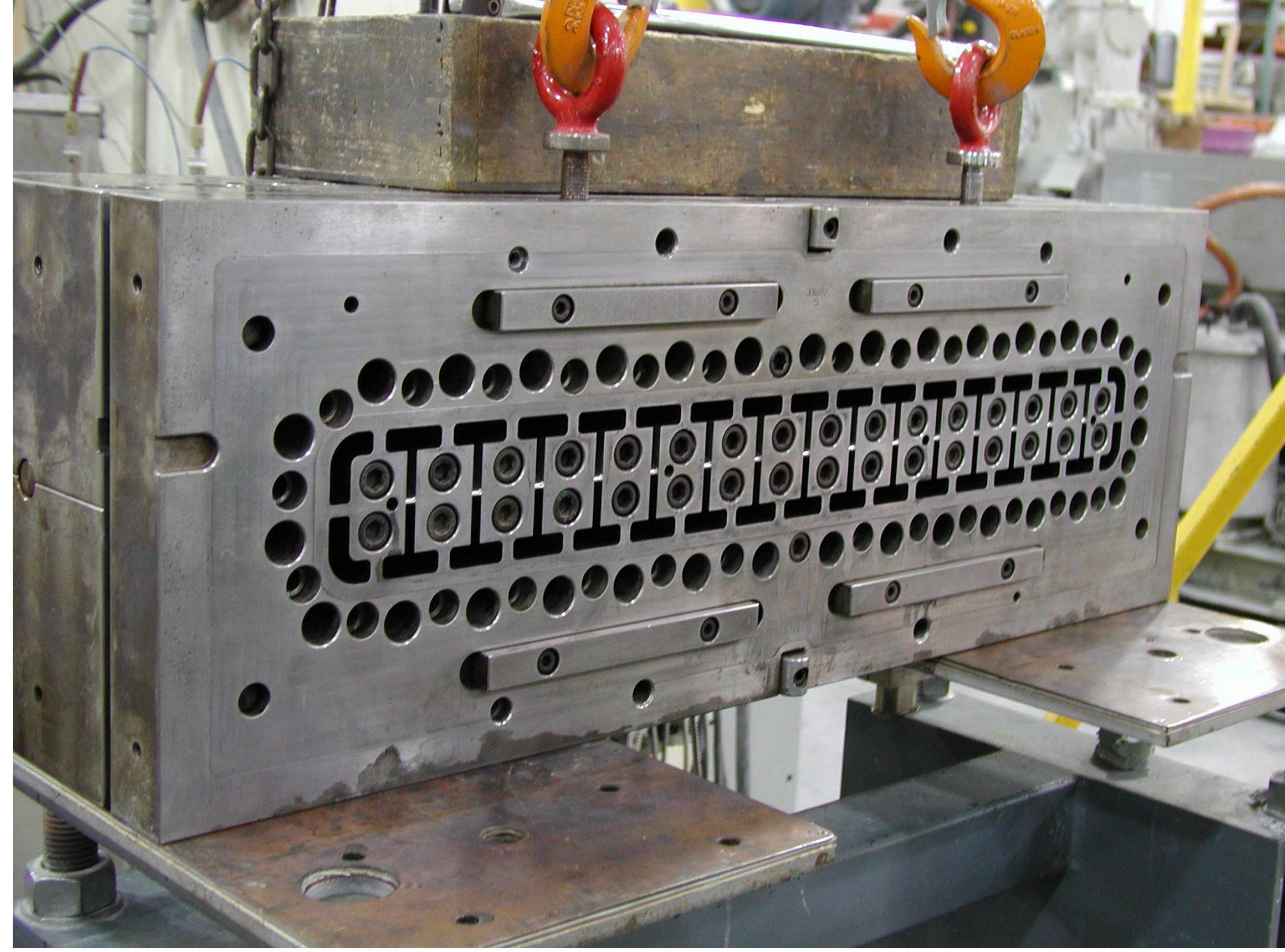
- **5,400 km delivered and tested**; 12,000 km required
- Kuraray continues to deliver on schedule despite earthquake and tsunami



Experiment progress:

PVC extrusions

- **Contracts in place for**
  - **PVC resin** for fixed price of $1 / lb
  - **Extruding** for fixed price of $0.96 / lb
- **Produced 1184 extrusions** for far detector which meet spec's; 23,000 required
- **Production currently running at 50%** full rate. Study time used to improve:
  - **Knitting**: There are ~70 points in the extrusion where two streams of melted resin merge and must "knit" together. Adjustments to die, flow rate, mixing, and melt temperature are likely to improve these joints.
  - **Reflectivity**: Vendor has sent several batches with unacceptably high fractions of rutile TiO_2; we require anatase which has better reflectivity. Working with vendor to ensure <2% rutile on all future shipments.
- **Plan to use thick walled extrusions only**
  - Original plan was to use thick for vertical planes and thin for horizontal
  - Having only thick simplifies construction, strengthens the detector, and expedites filling
  - Active fraction reduced from 71% to 66%



Experiment progress:

PVC modules

- Two 16-cell extrusions are assembled into 1 32-cell module at U. Minnesota factory. Fibers installed and routed, ends sealed.

Moving far detector extrusions off 2-to-1 glueing table

- Two 16-cell extrusions are assembled into 1 32-cell module at U. Minnesota factory. Fibers installed and routed, ends sealed.

- Factory moved to large warehouse for far detector production.
- Much work has gone into understanding and redesigning the manifold cover which developed cracks on the prototype. New design is stronger and eliminates all stress concentrators. First parts expected in July.

Experiment status:

Assembly

- Prototype pivoter is completed and tested (pictured at right)
- Ash River pivoter is under construction.
- 5 outfitting workshops held in past 6 months to refine plans in light of experience with prototype detector
- Detector structure modified to be simpler and stronger by opting to use only a single style of PVC extrusion. Safety factor increased from 1.3 to 3.1 which allows for immediate filling of blocks with scintillator.
- Planning to have first block in place and filled prior to March 2012 shutdown

Block pivoter prototype at CDF

Backup slides: NDOS commissioning and running

NDOS operations

- All basic functionality is in place for run control and data monitoring in shared (NOvA/ MINOS/MINERvA/ MiniBooNE) Neutrino Control Room in WH12NW.
- We've been operating NDOS in a mode where during the day priority is given to commissioning work and testing. Typically button up and run from 8 pm to 8 am.
- Recent live time during past month is 95% between hours of 8 pm and 8 am.
- Stress tests of DAQ indicate that the system runs with enough head room to accommodate the rates at the far detector.

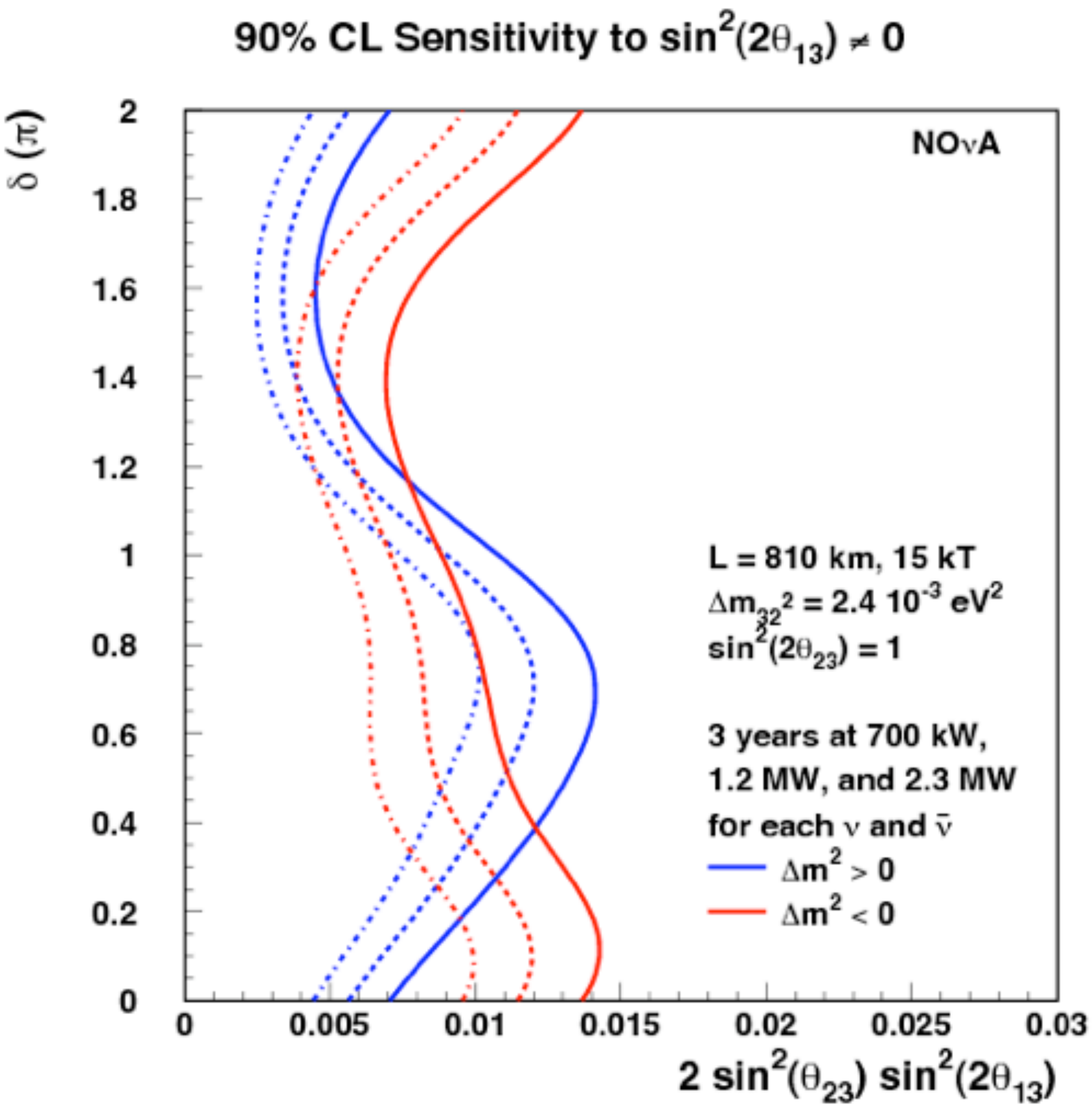
NDOS Computing

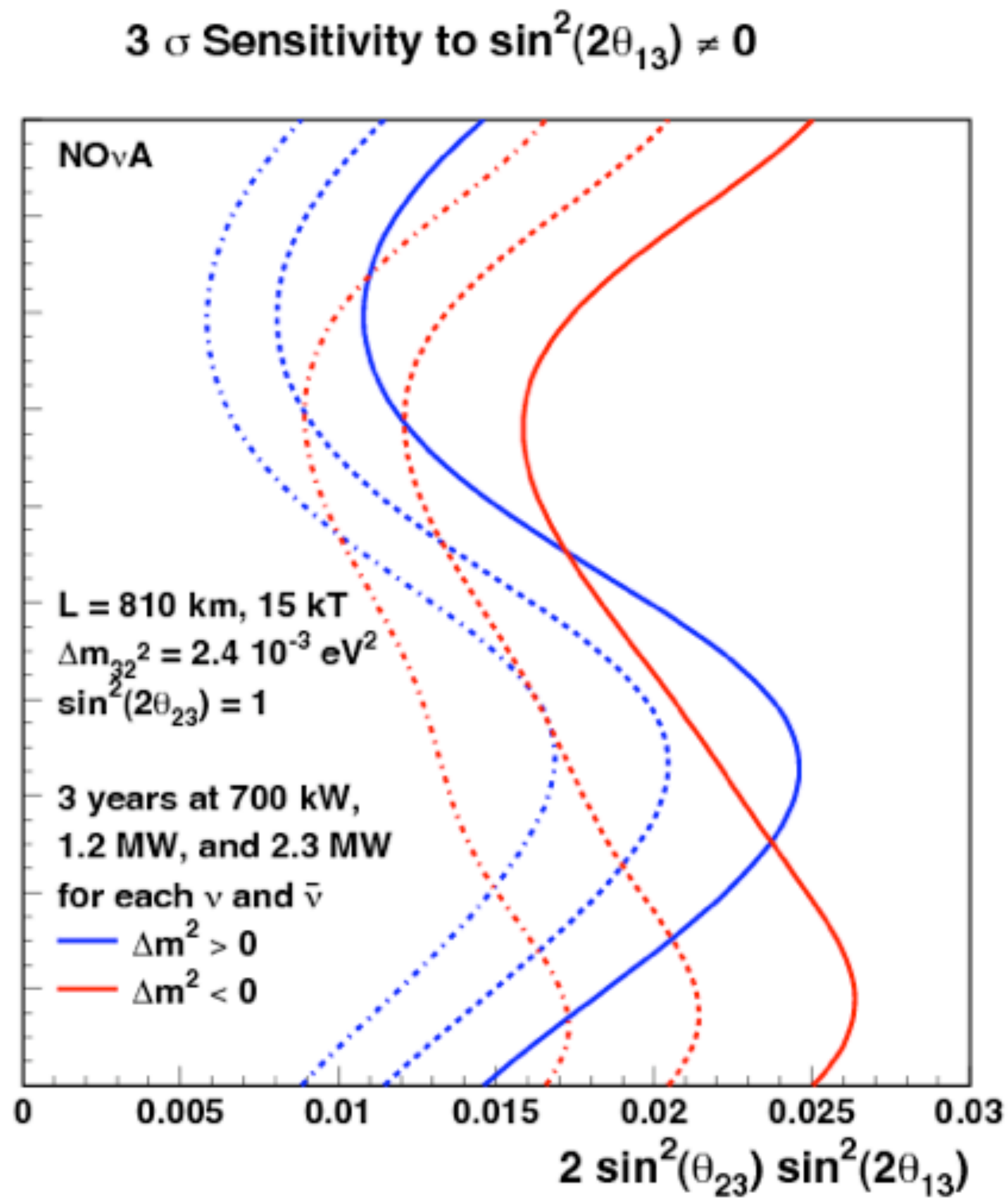
- Data and Monte Carlo processing
    - To date, we've recorded 13.7 TB of data in NDOS
    - Reprocess Monte Carlo (cosmic rays, NuMI, BNB) and data roughly every 6 weeks and maintain a regular "keep up" processing. Routinely use 500 grid nodes during reprocess. Data takes ~1 day, MC takes ~1 week.
    - Keep up process makes **new data available offline within ~2 hours** of its being recorded
- **Migrated our code framework to ART** which is maintained by FNAL computing division and is used by mu2e and liquid argon experiments. A slightly bumpy transition over about 6 weeks but we've had good support from computing division during the transition.
- **40 users in collaboration use 5 interactive nodes** on virtual machines shared across the Intensity Frontier. Full data sample is available to this cluster. Transition to the virtual machines was not 100% smooth, but with good support from CD we've recovered disk access performance.
- **Despite short-term bumps, we expect to reap long term gains by using common solutions that are supported by FNAL CD**

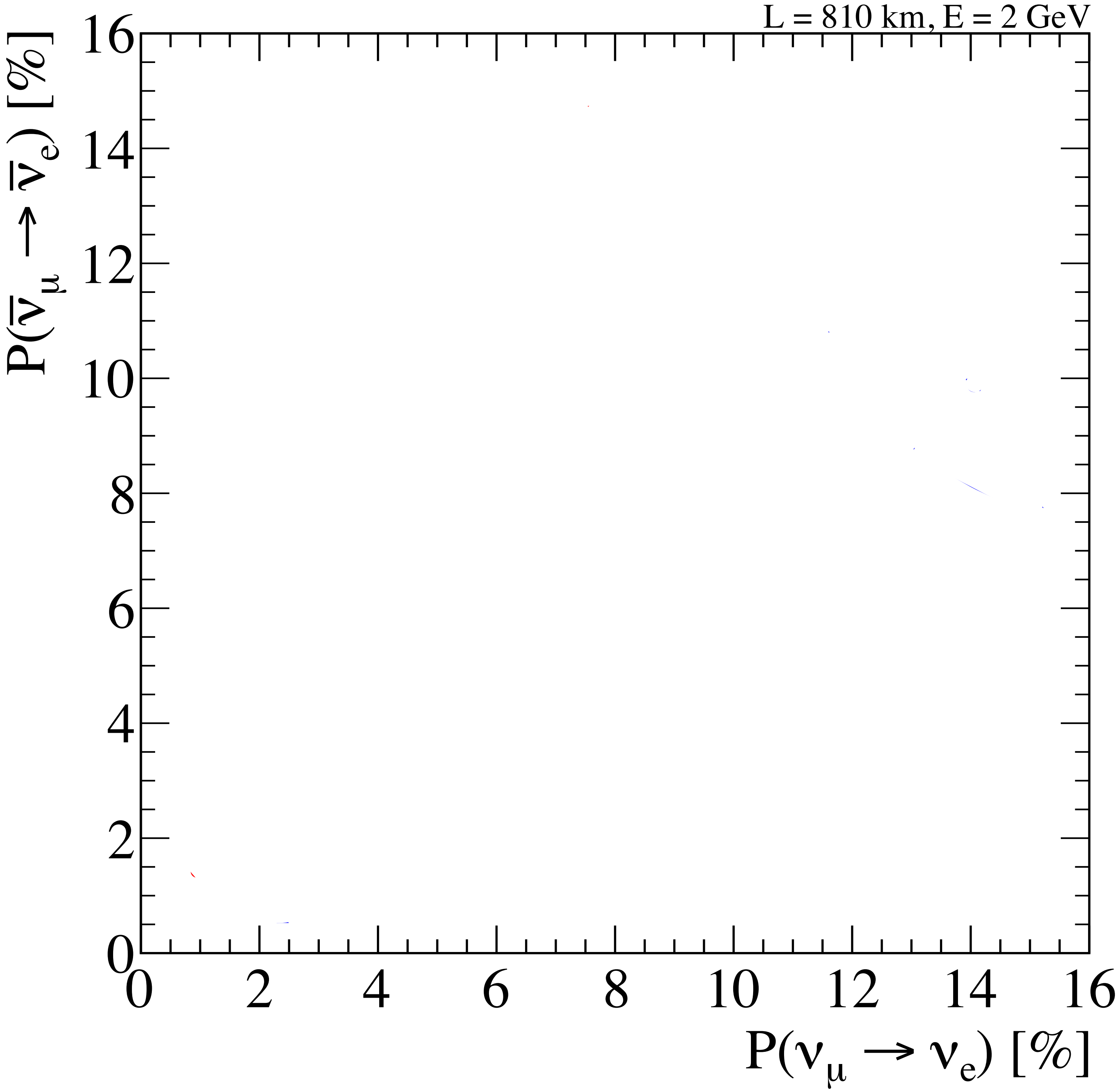
Backup slides: NOvA physics sensitivities

All NOvA physics plots are available at this public web address:
http://www-nova.fnal.gov/plots_and_figures/plots_and_figures.html

Sensitivity to $\nu_\mu \rightarrow \nu_e$ Oscillations





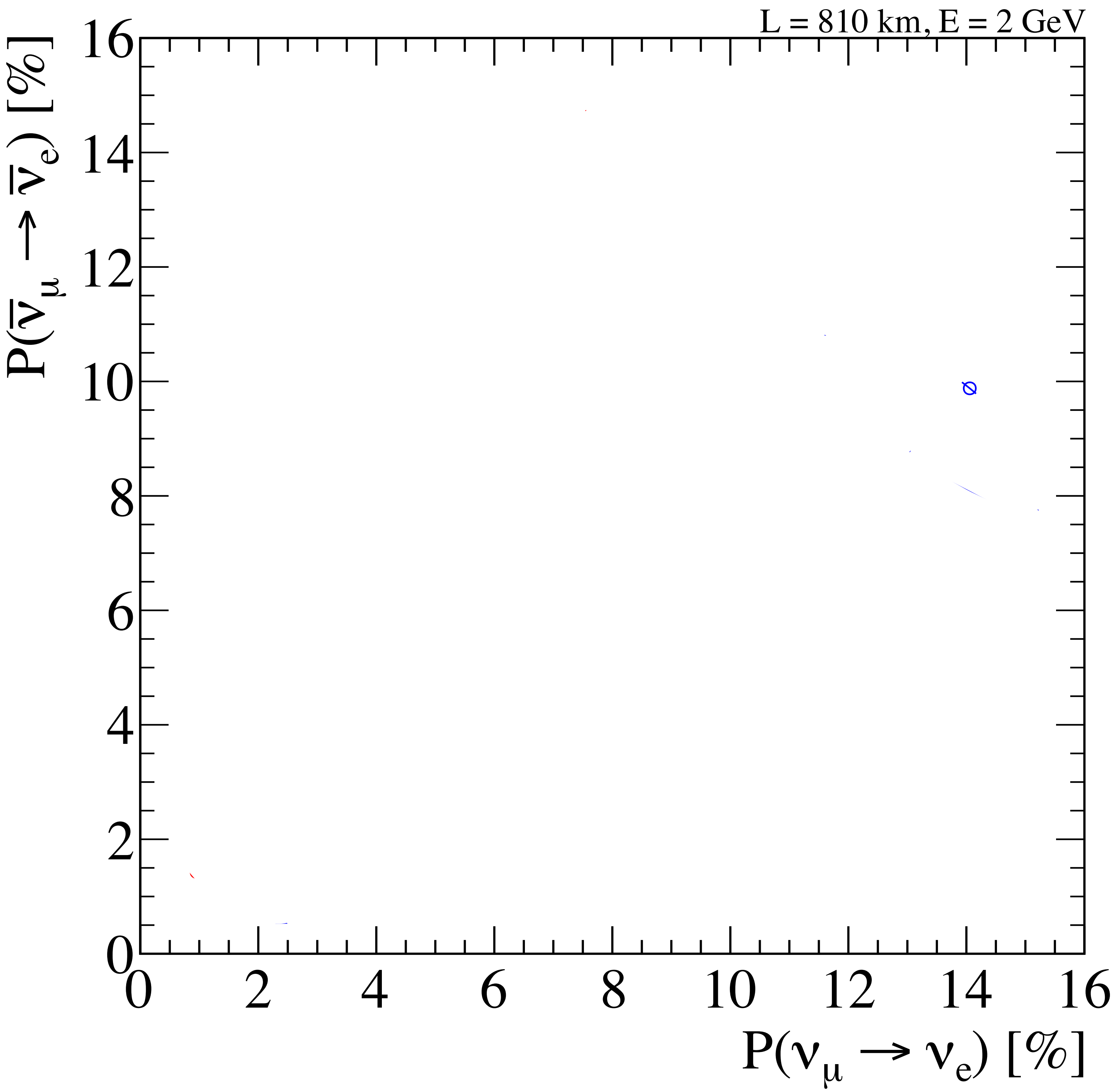


Using a muon neutrino beam, we have two basic observables

1. $P(\nu_\mu \rightarrow \nu_e)$ for neutrinos
2. $P(\nu_\mu \rightarrow \nu_e)$ for anti-neutrinos

We can plot these two observables as a function of the remaining unknowns θ_{13}, δ_{CP}, and mass hierarchy.

Principle of the NOvA Experiment



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$\theta_{13} = 15^o$

$\Delta m^2_{13} > 0$ (“Normal hierarchy”)

$\delta_{CP} = 0$

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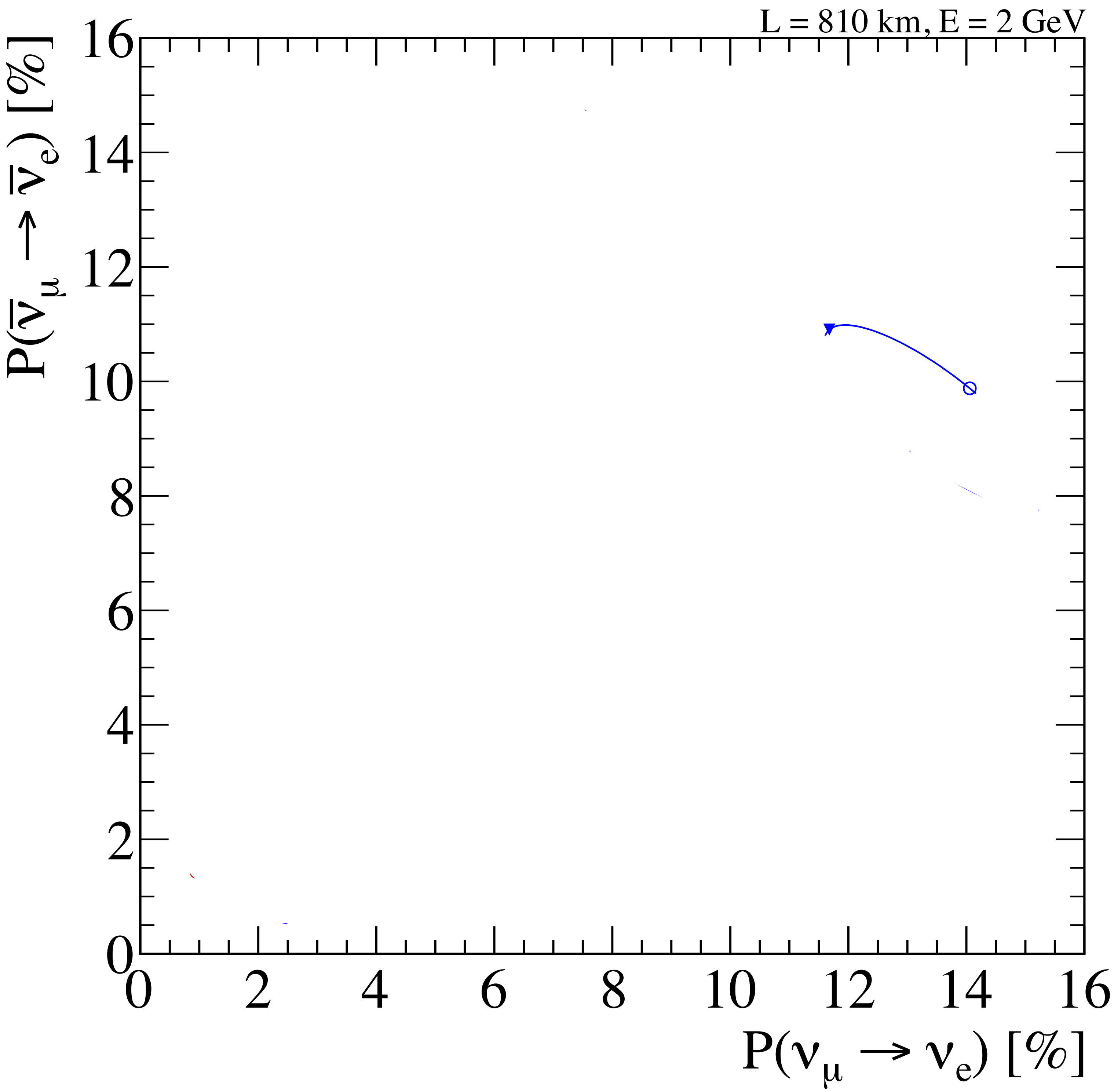

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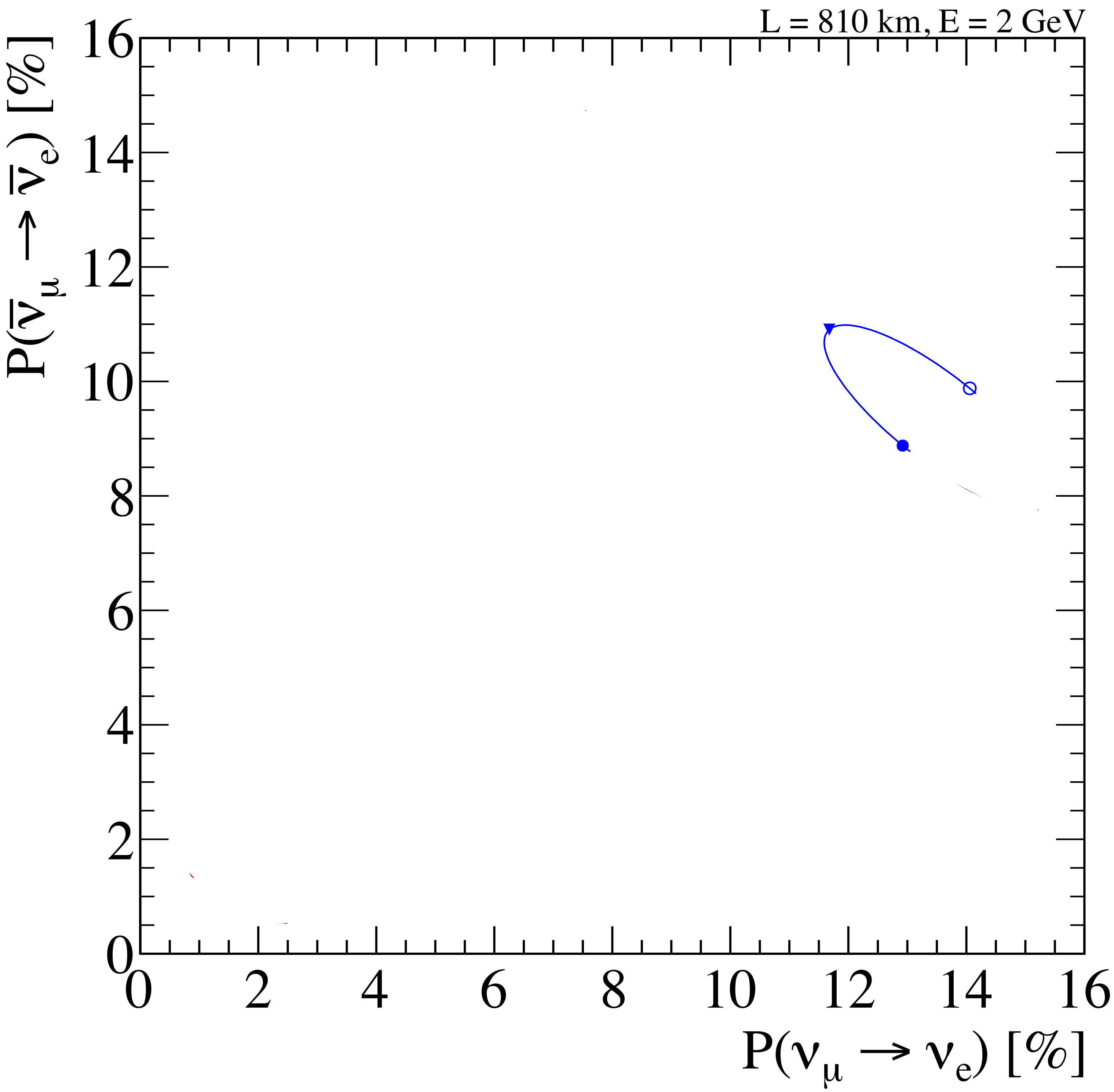

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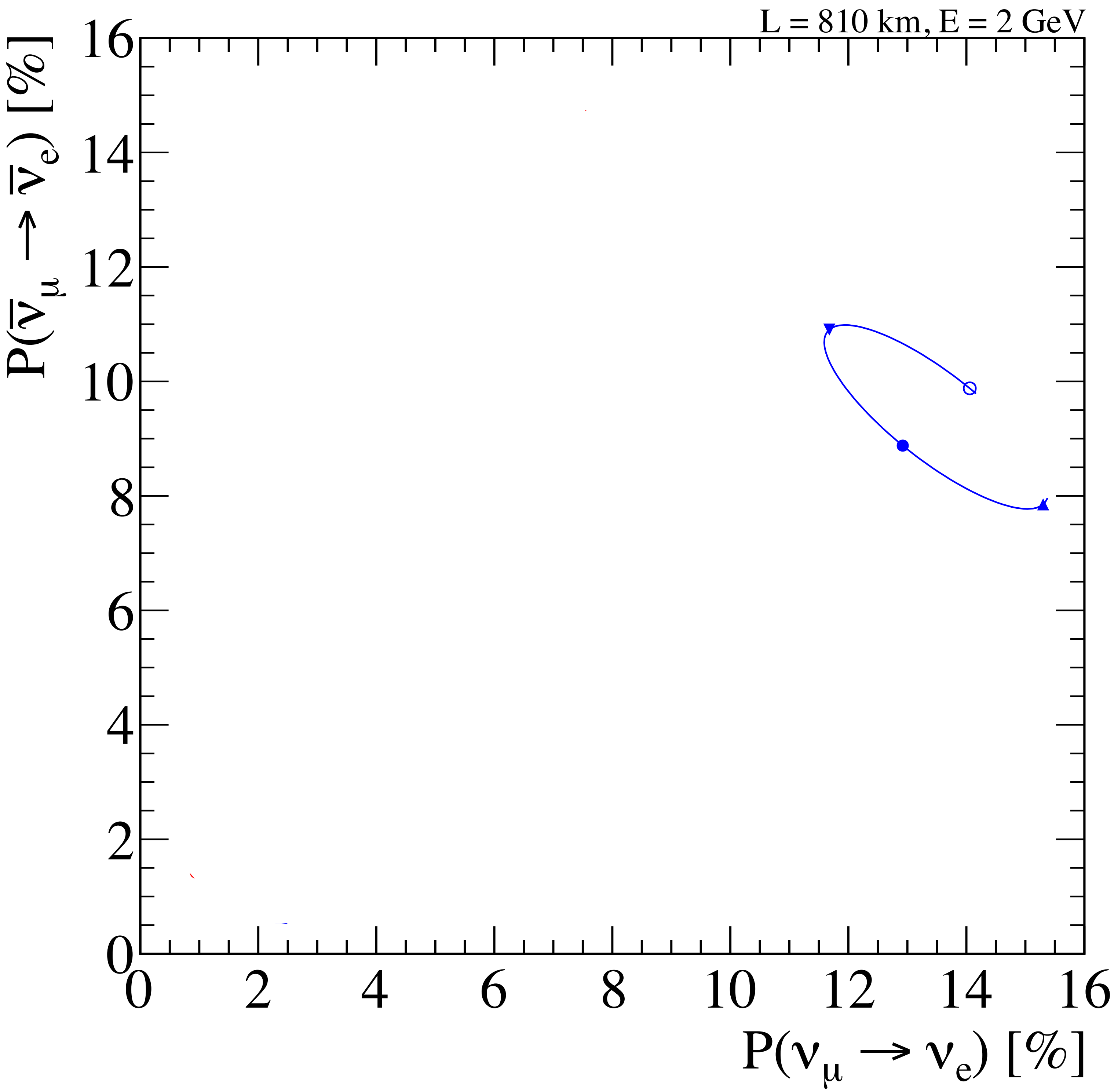

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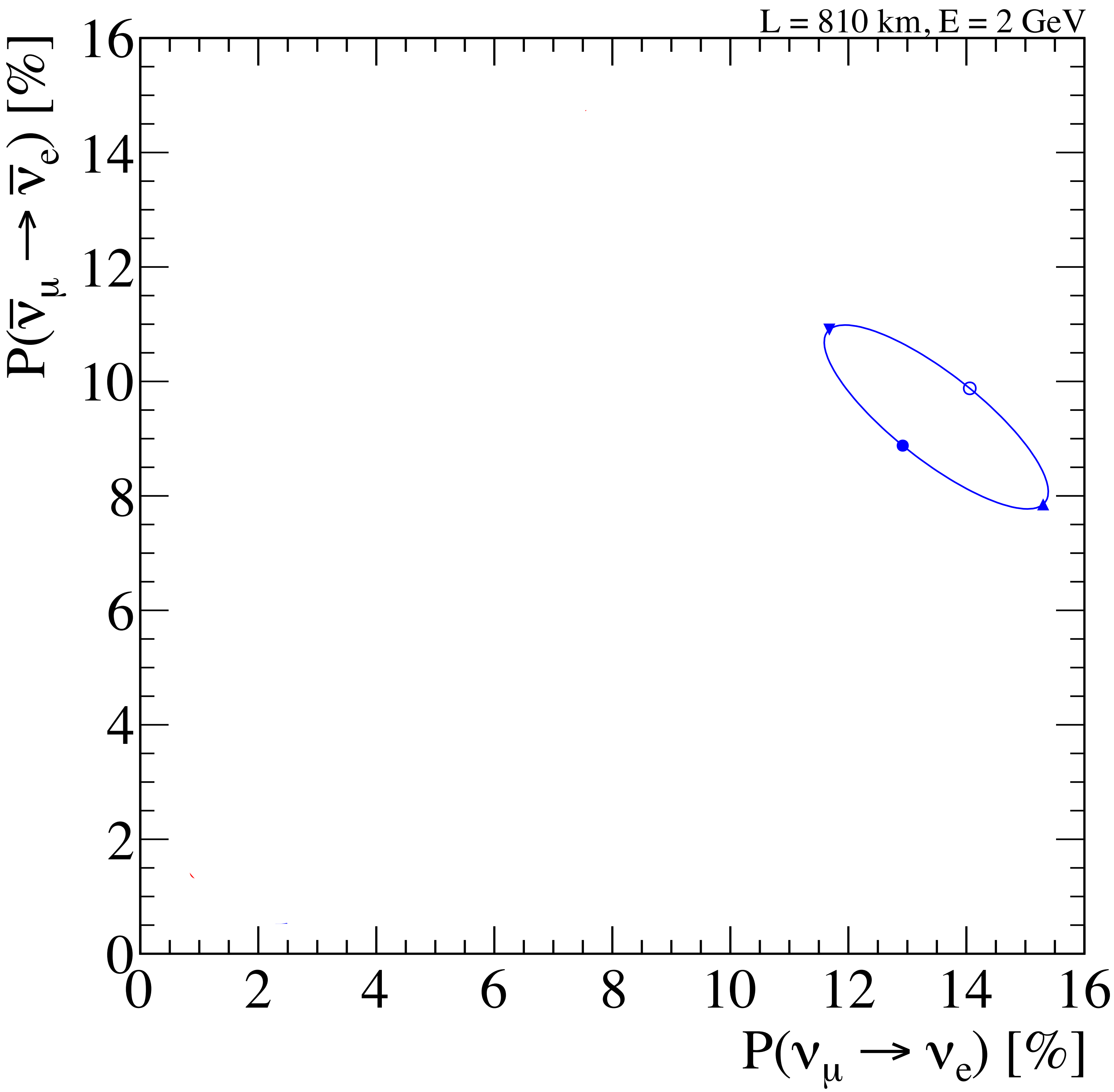

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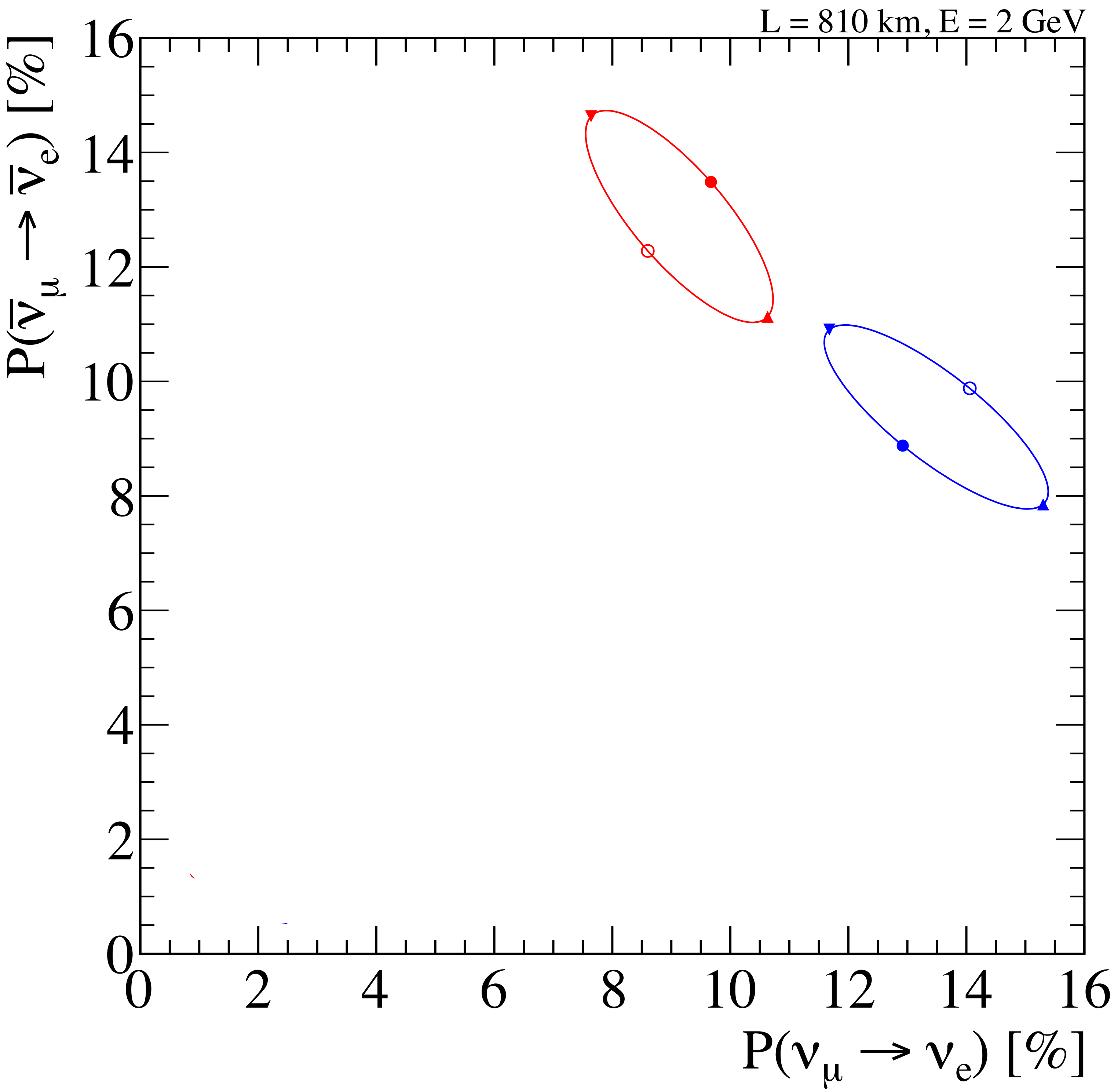

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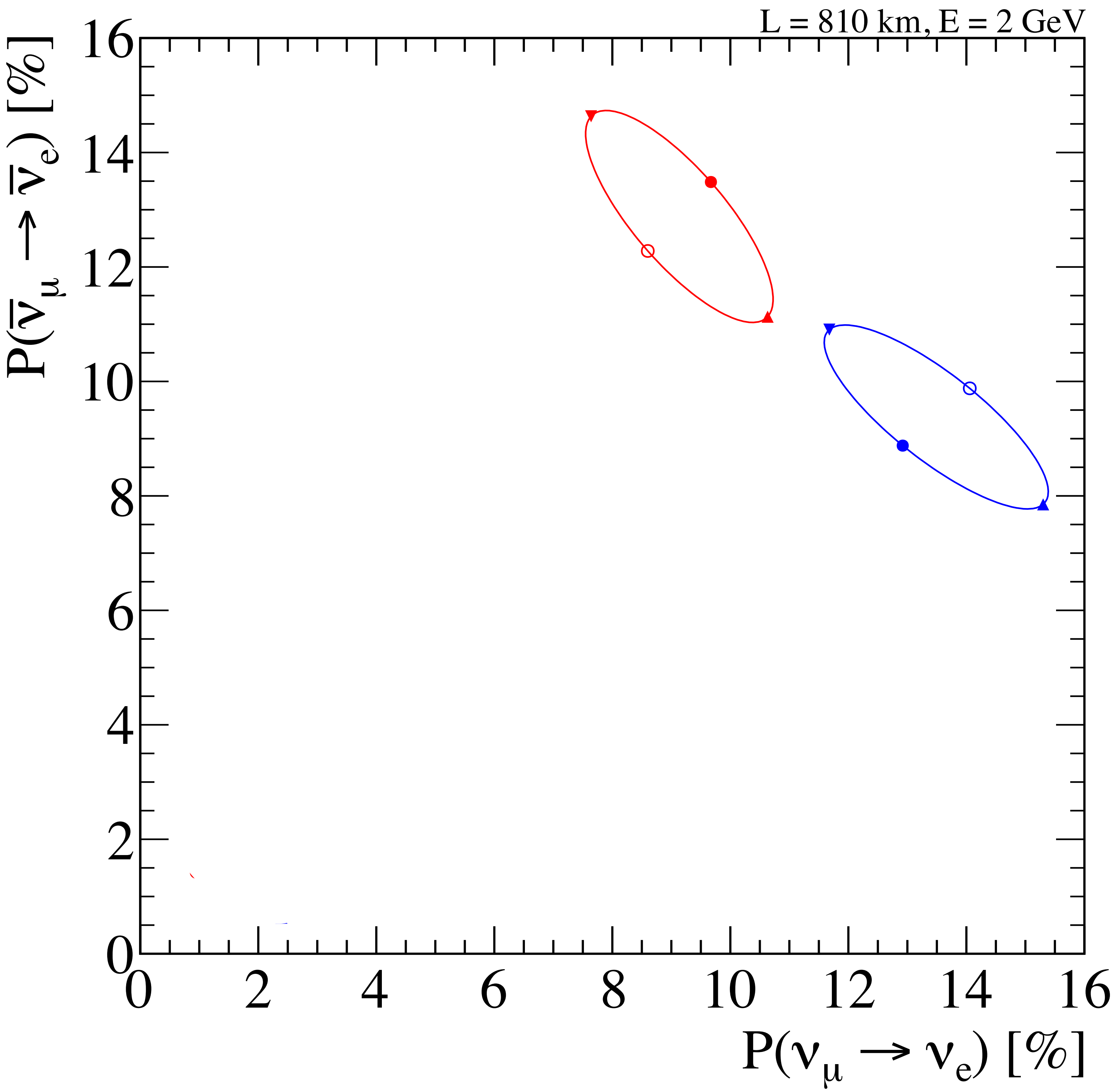

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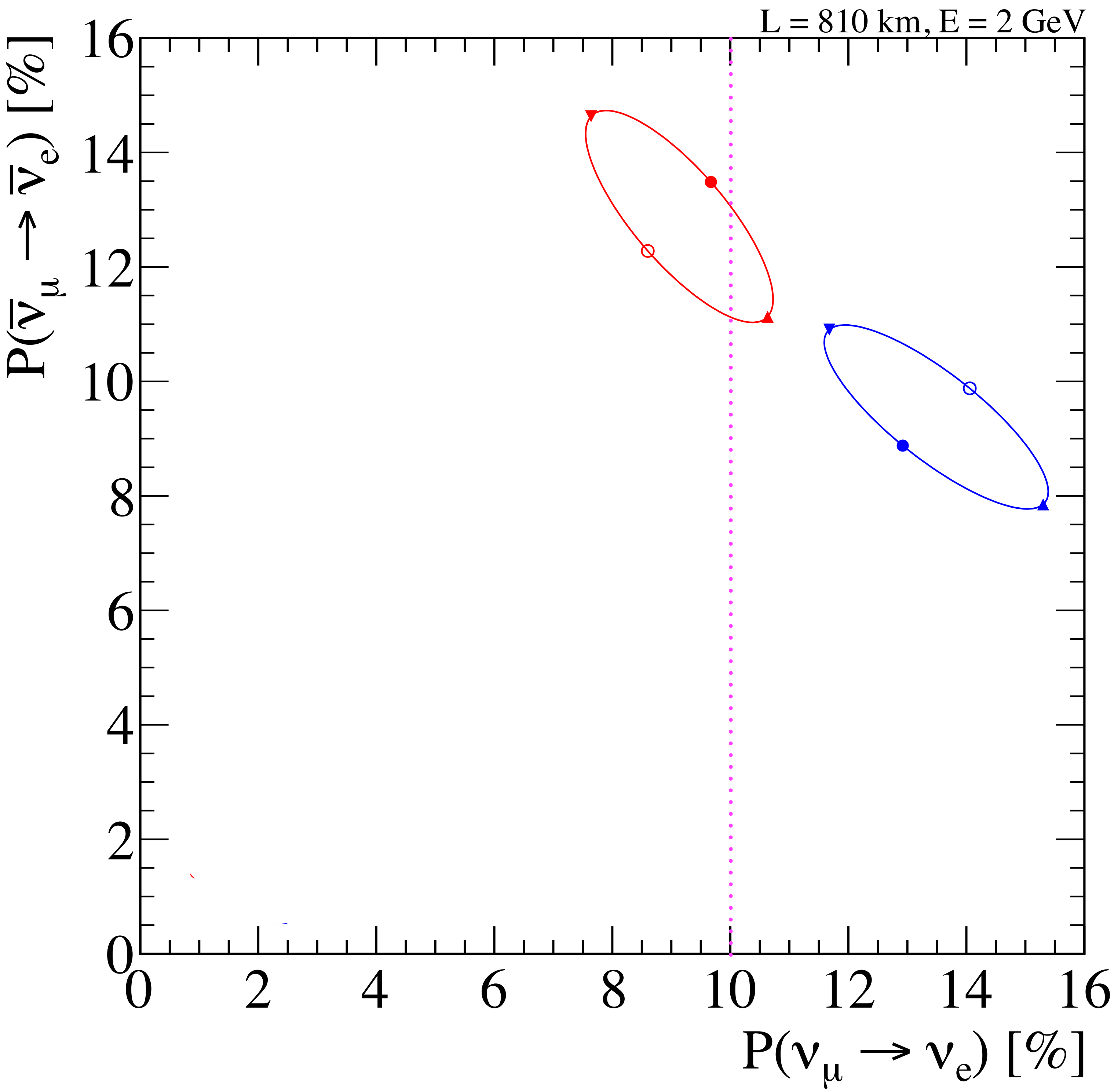
Perfect measurements of the two oscillation probabilities answer all remaining questions if θ_{13} is large enough.

Principle of the NOvA Experiment



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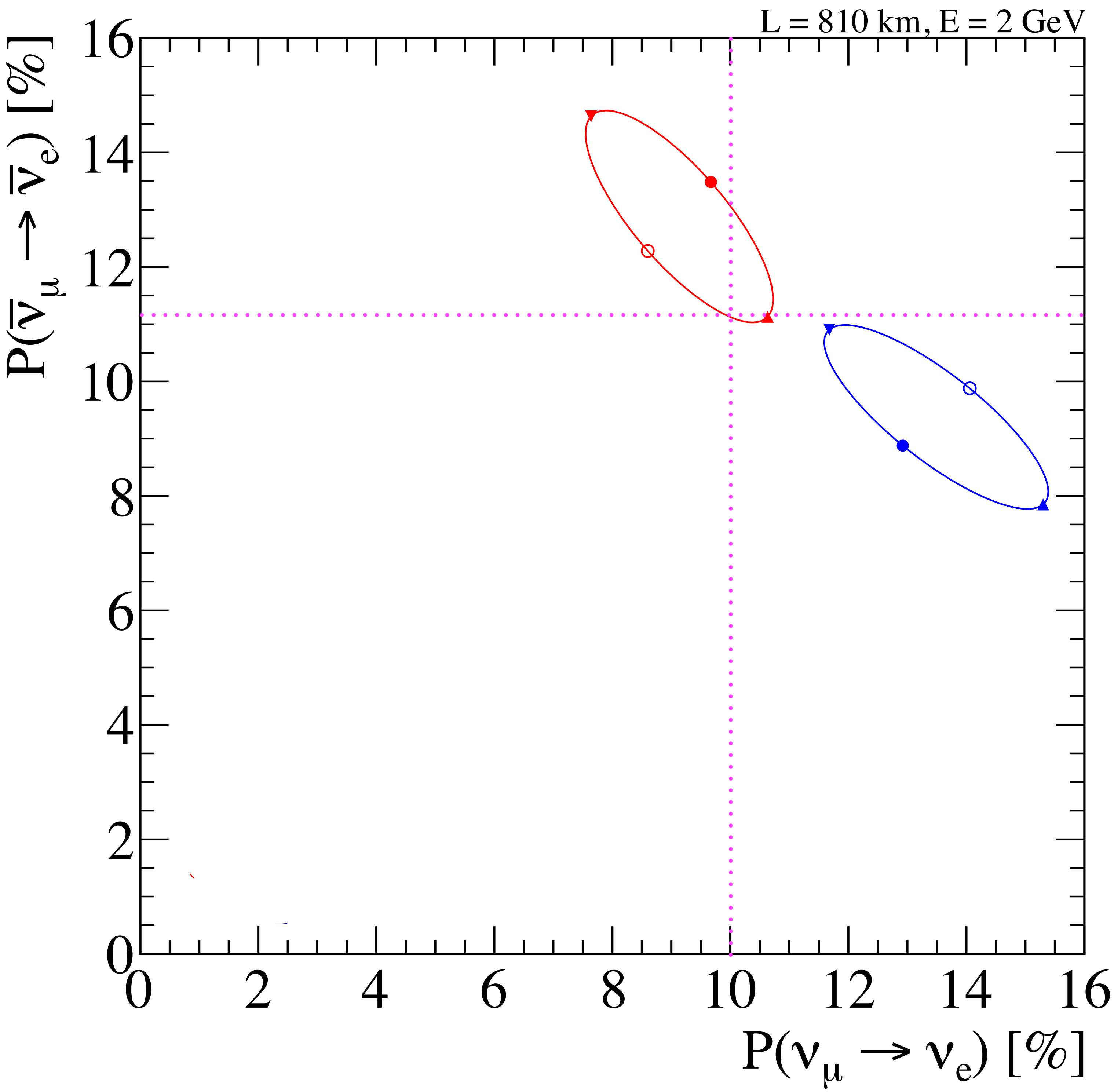

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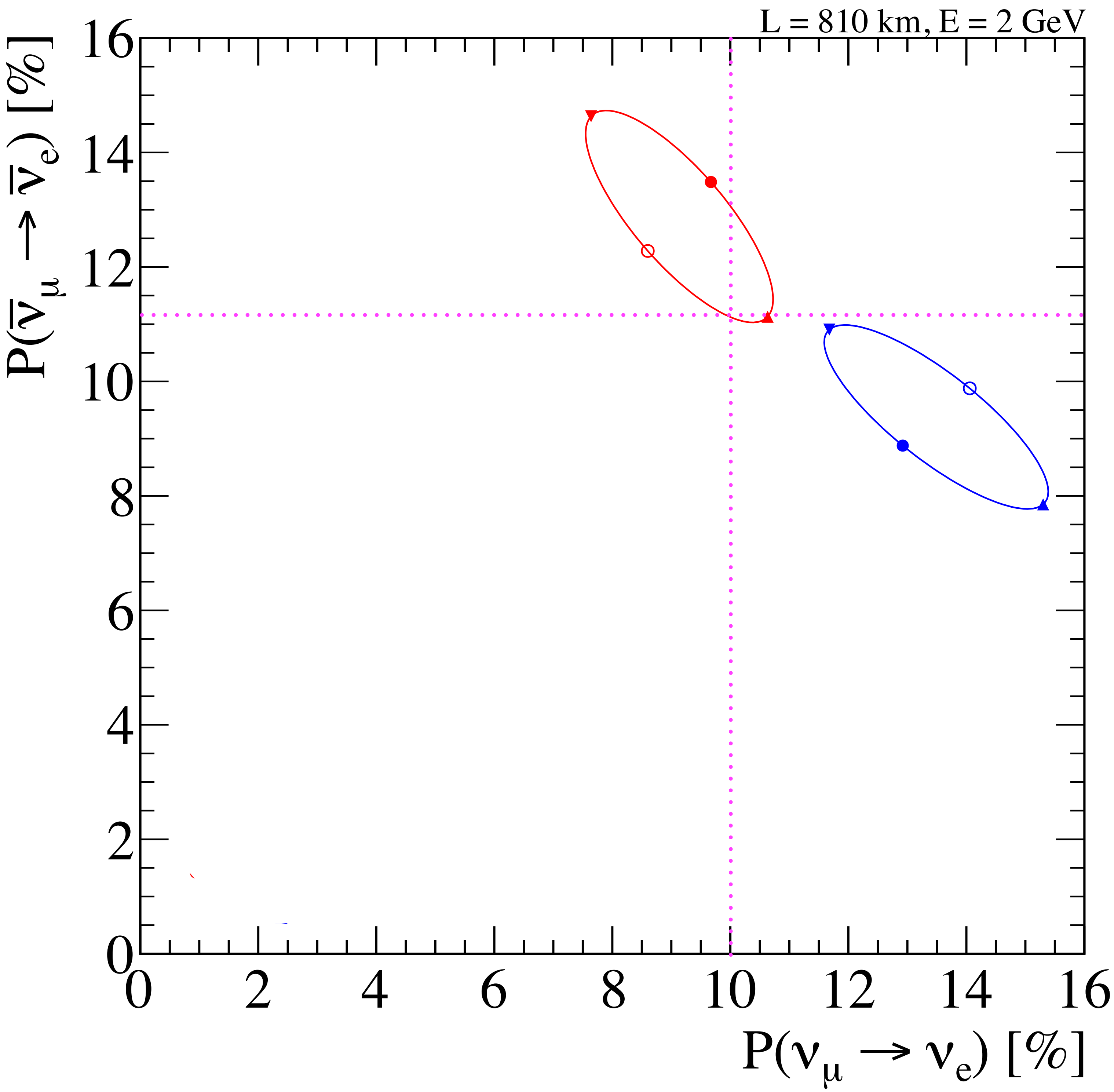

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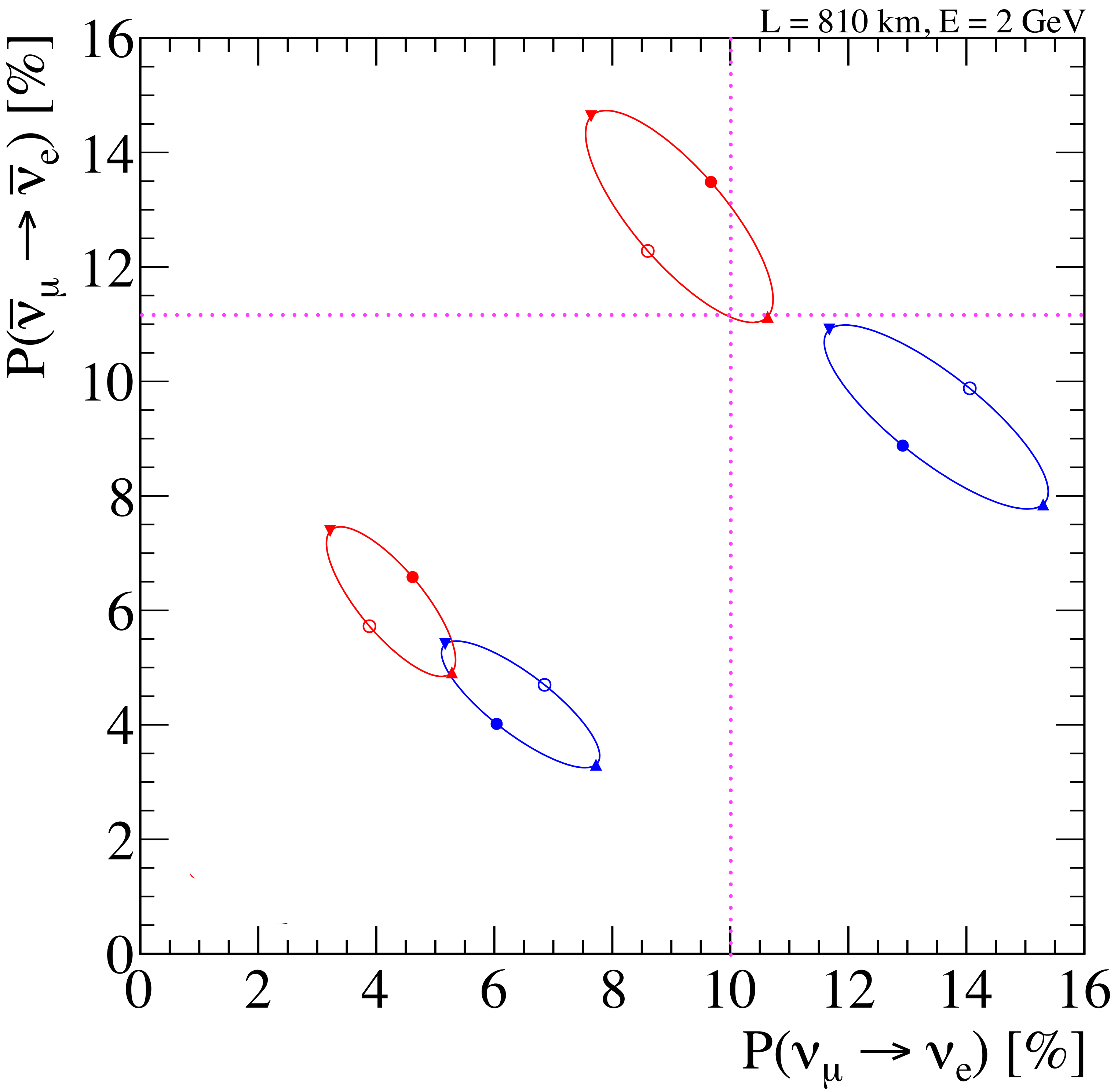
For small θ_{13} there are inherent ambiguities between hierarchy choice and δ_{CP}. However, even in these cases we learn something about δ_{CP}.

Principle of the NOvA Experiment



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θ_{13} = 15°, 10°

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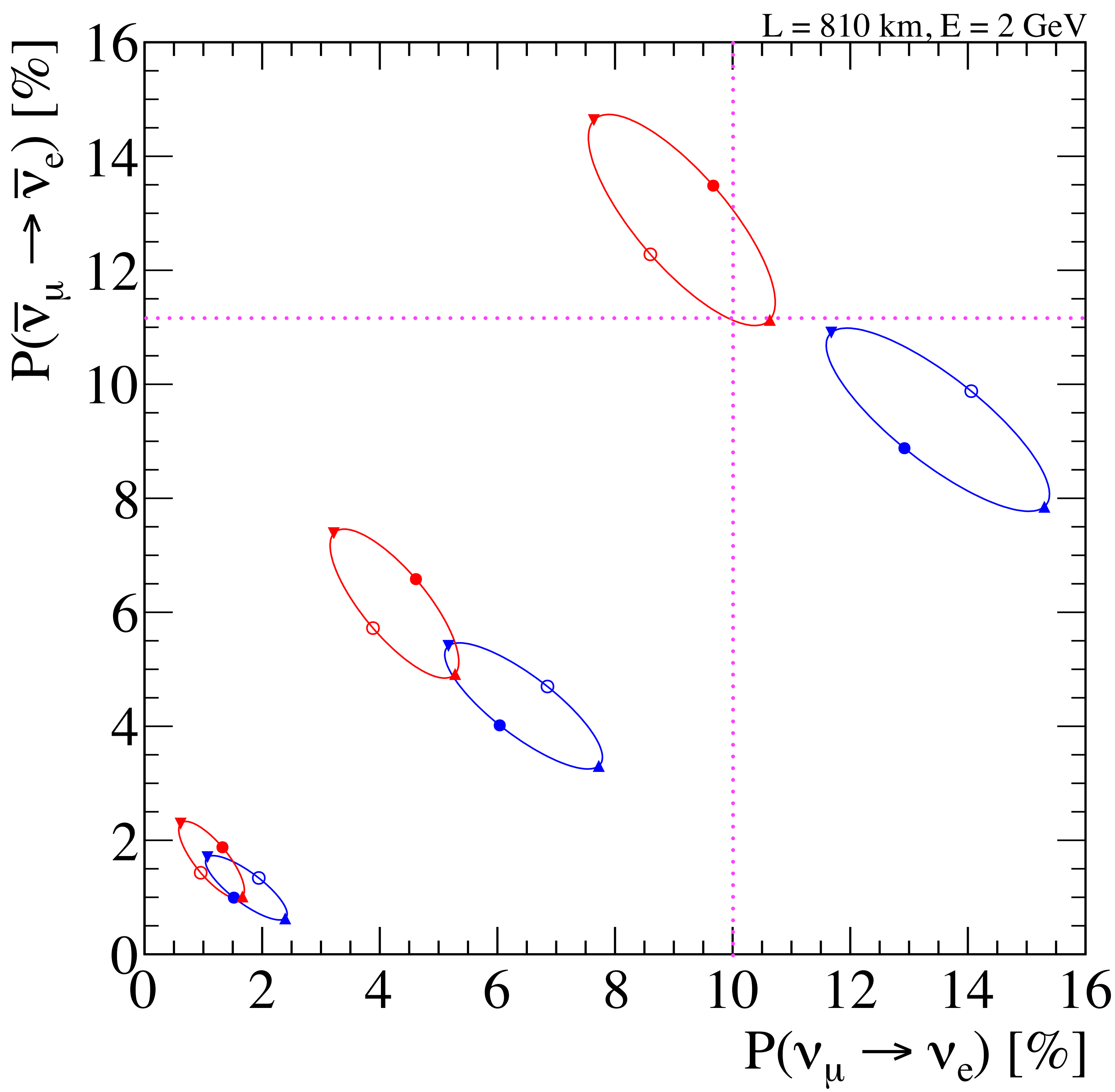

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θ_{13} = 15°, 10°, 5°

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δ_{CP} = 0, ▼π/2, ● π, ▲3π/2, 2π

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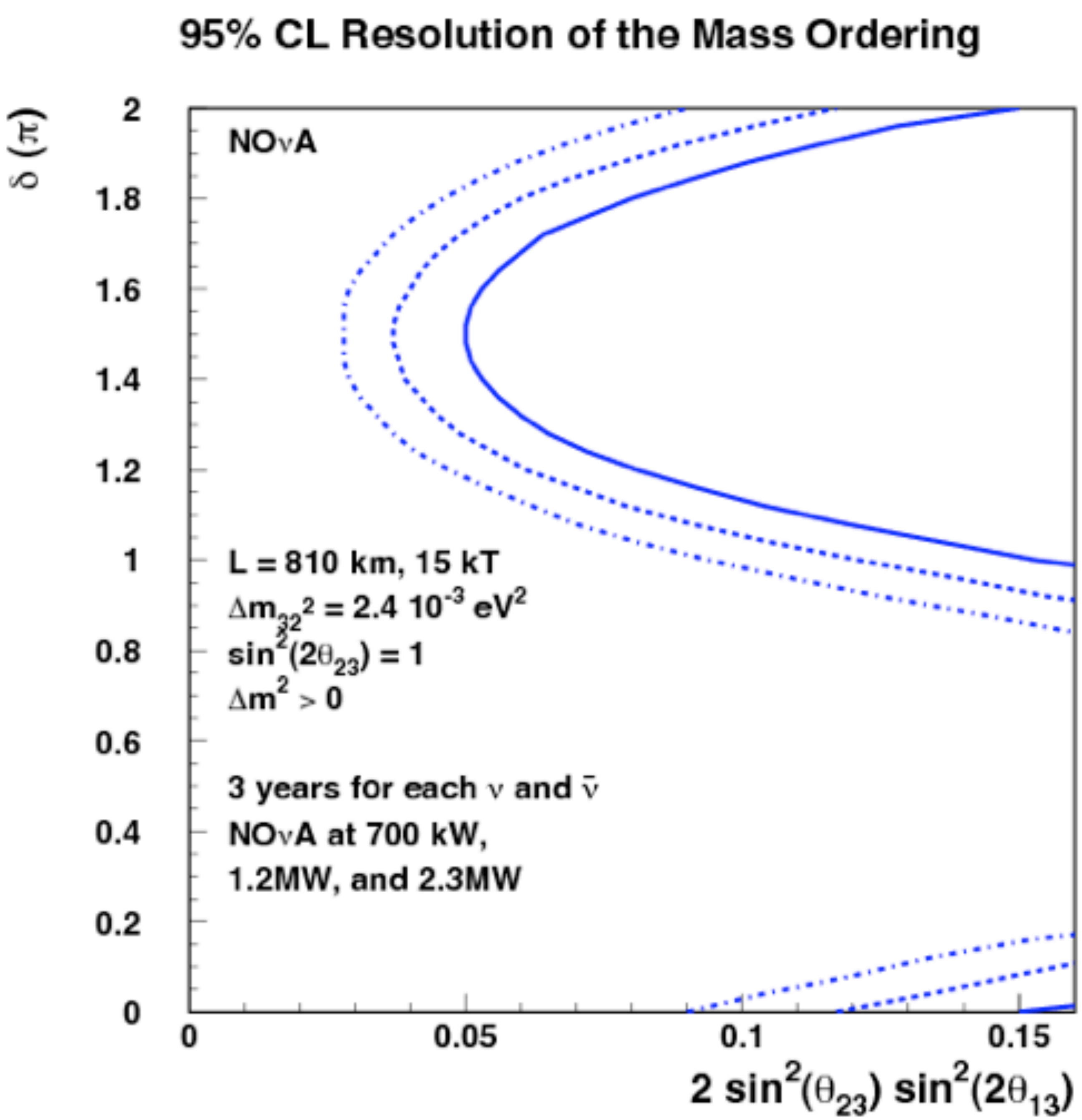
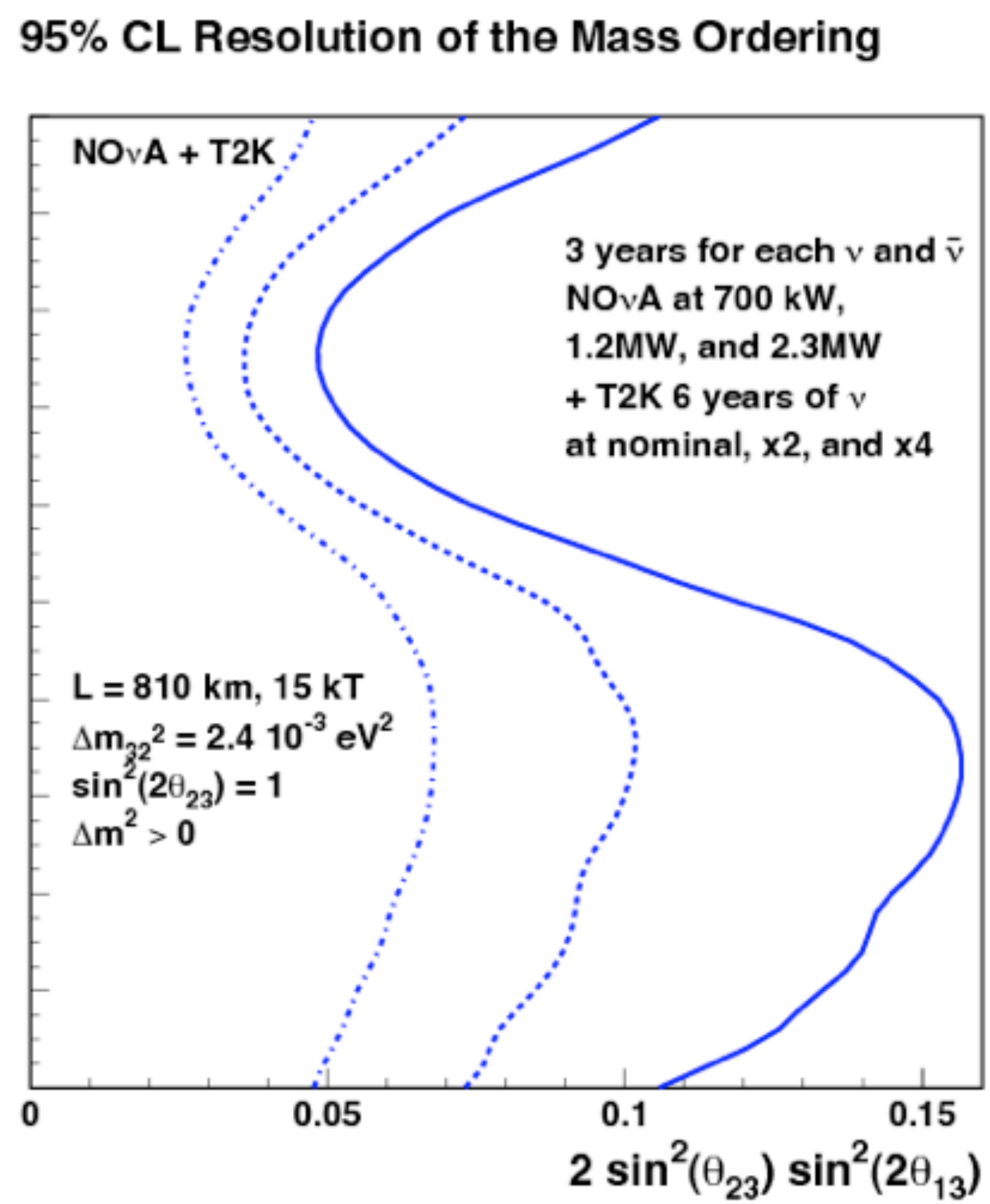
Resolution of the mass hierarchy

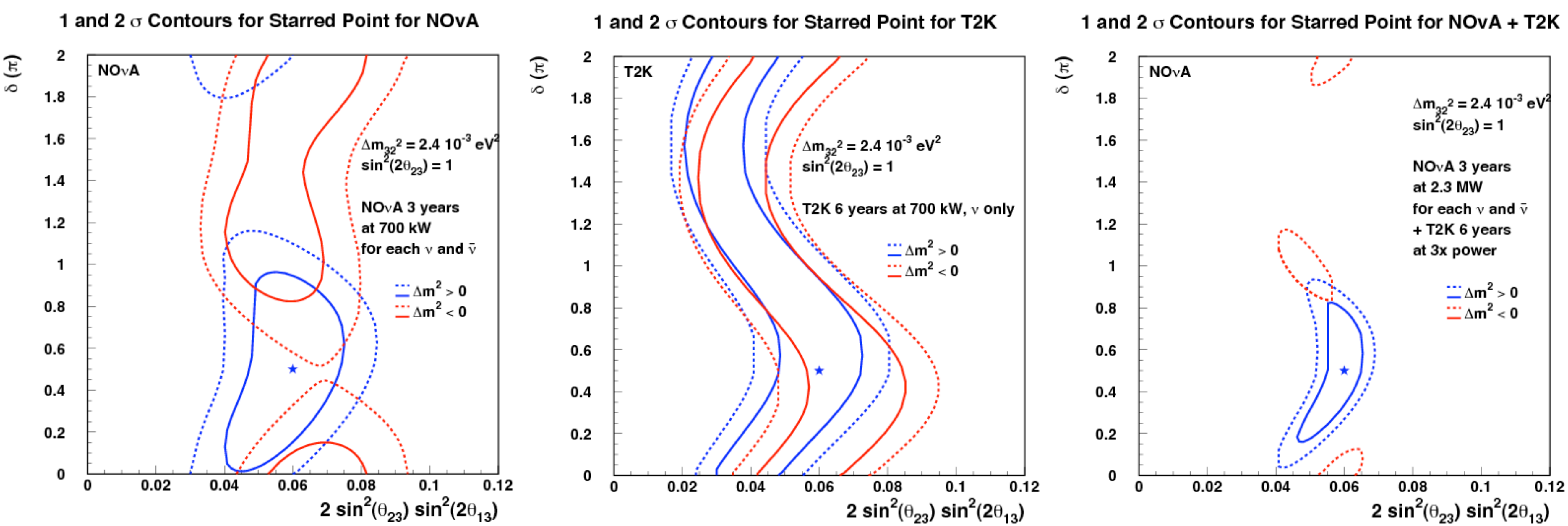


Compare NOvA's neutrinos to NOvA's anti-neutrinos



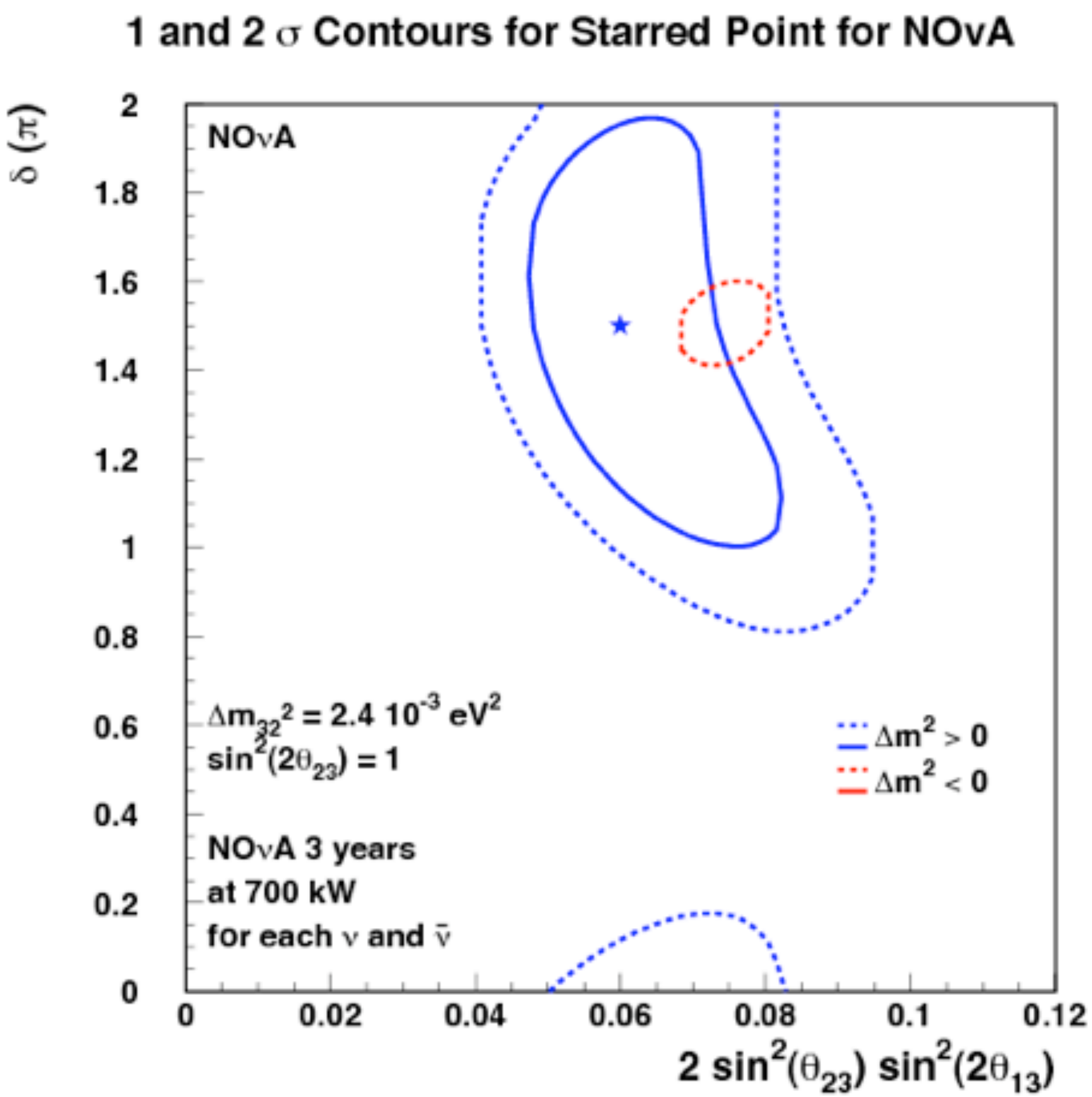
Compare NOvA's neutrinos w/ matter effect to T2K's neutrinos ~w/o matter effect

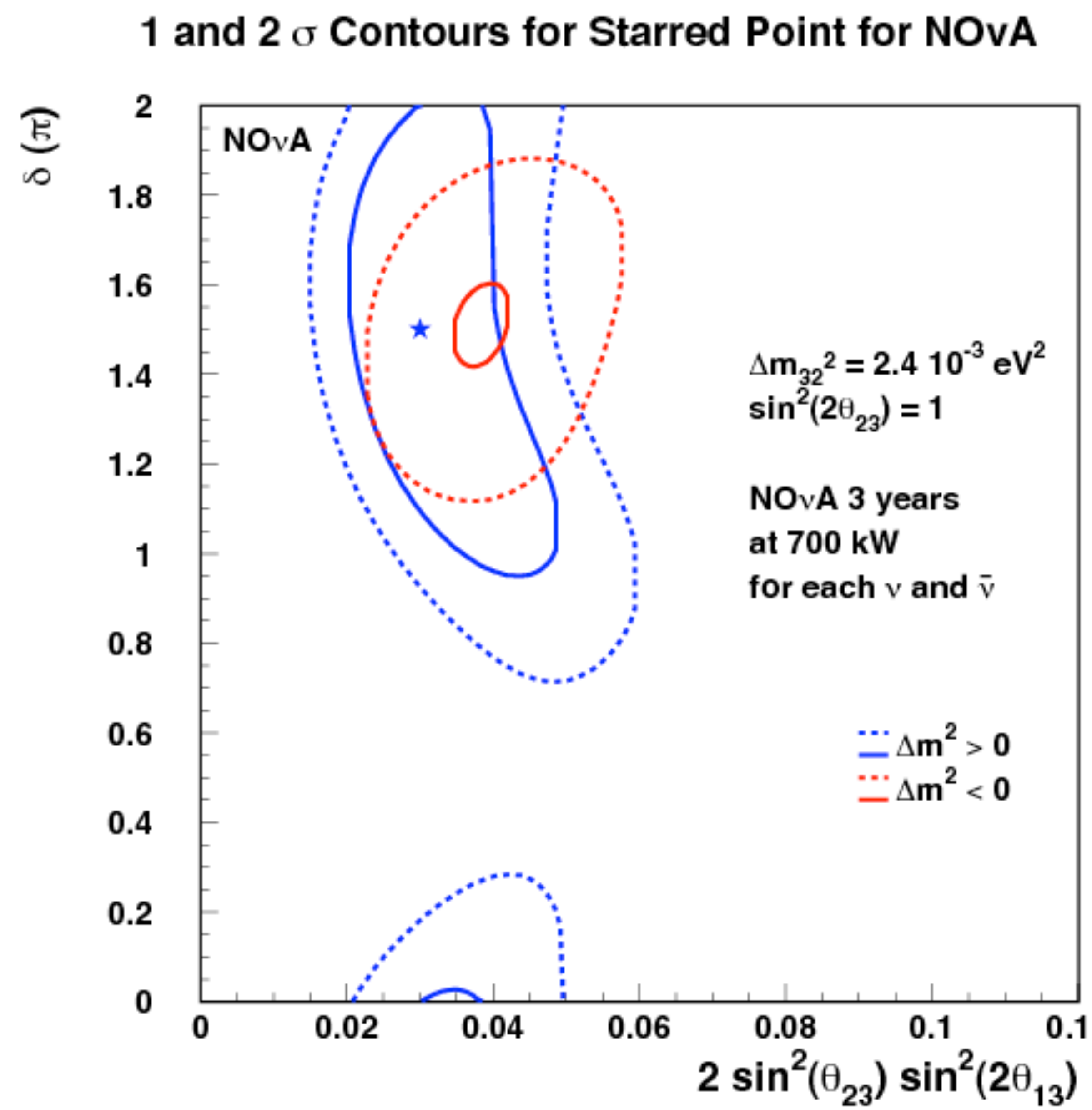
Combining NOvA and T2K in lower half plane



In this region combining NOvA and T2K helps. T2K's "S" only intersects NOvA region in lower half plane

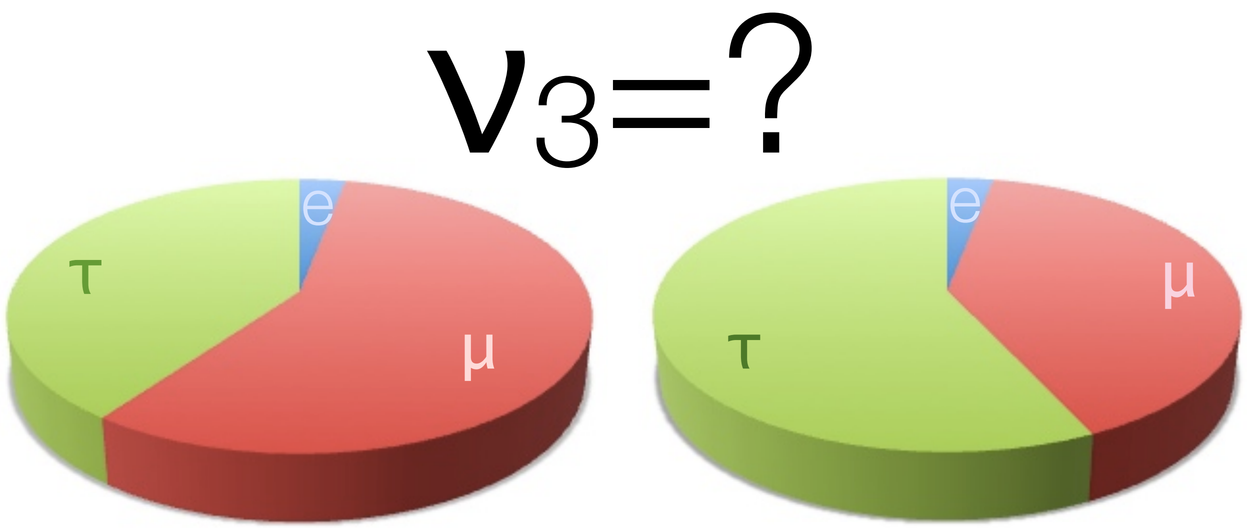
Begin study of δ_{CP}



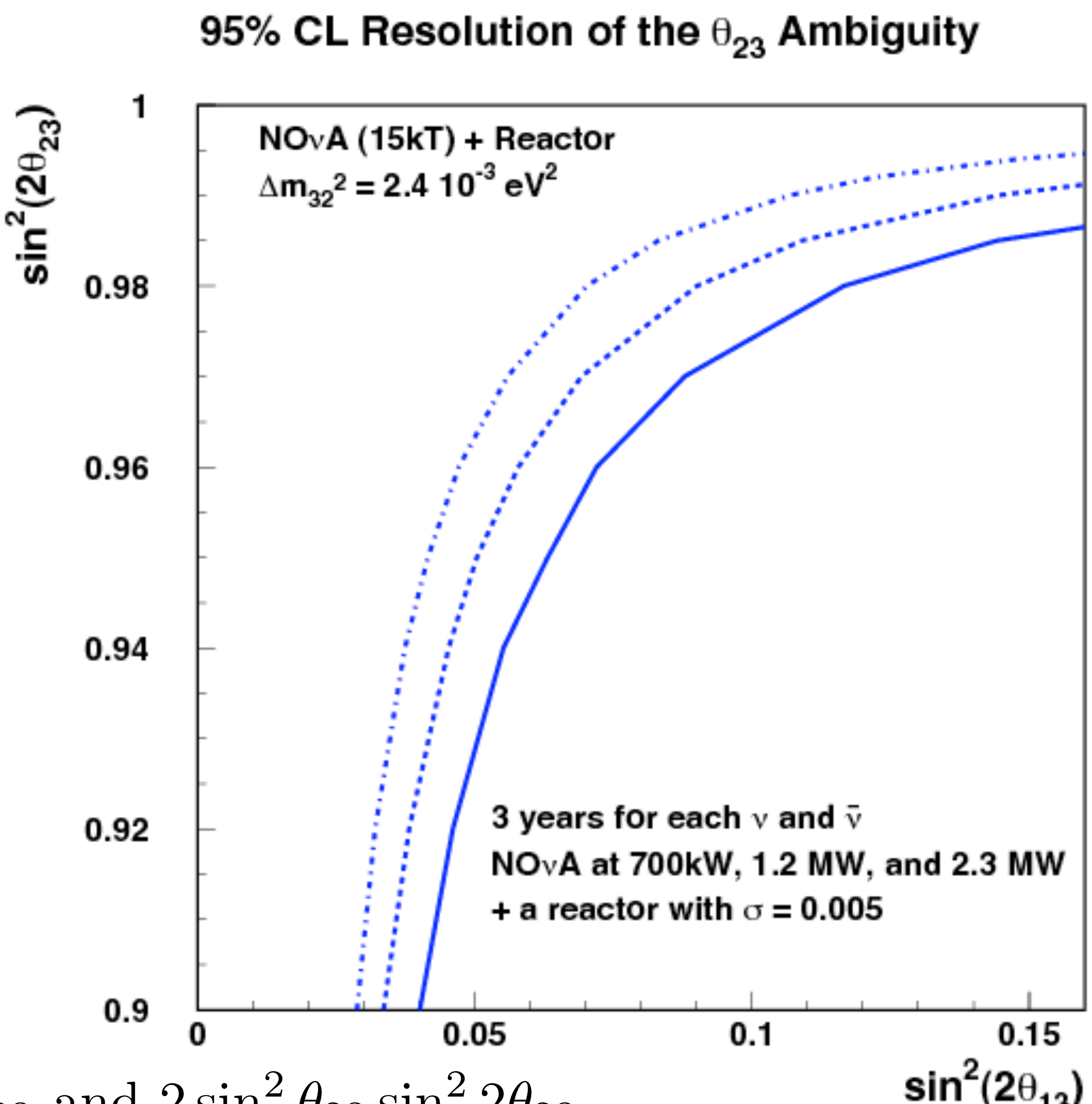


δ_{CP} sensitivity is almost independent of θ_{13}. Reason is that while event rates increase with θ_{13} the asymmetry $(P - \bar{P})/(P + \bar{P})$ shrinks.

θ_{23} Quadrant: NOvA + Reactor



$\theta_{23} = 40^\circ$ $\theta_{23} = 50^\circ$



- Long baseline experiments measure $\sin^2 2\theta_{23}$ and $2\sin^2\theta_{23}\sin^2 2\theta_{23}$
- Reactor experiments measure $\sin^2 2\theta_{13}$
- Combination allows measurement of $\sin^2 2\theta_{23}$ and $\sin^2\theta_{23}$